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ETIOLOGY AND INTEGRATED CULTURAL AND CHEMICAL CONTROL OF SEED DECAY, DAMPING-OFF AND ROOT ROT OF CHICKPEA

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Etiology and Integrated Cultural and Chemical Control of Seed Decay, Damping-off and Root Rot of Chickpea

Final Report

For

Saskatchewan Agriculture Development Fund

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EXECUTIVE SUMMARY

- Surveys of chickpea fields found severe damage caused by seedling blight and root rot. Three pathogens, *Pythium*, *Fusarium* and *Rhizoctonia*, were found in infected plants and shown to cause seedling blight under controlled conditions.
- Field and greenhouse experiments were conducted to evaluate chemical seed treatments for reduction of seedling blight.
    - Apron and other metalaxyl formulations improved emergence and yield of chickpea in *Pythium*-infested soil.
    - Formulations including Crown, Maxim, or Vitaflo-280 improved emergence and yield of chickpea in *Fusarium*-infested soil.
    - Formulations including Captan, Dividend, Vitaflo-280, Apron Maxx or Crown improved emergence of chickpea in *Rhizoctonia*-infested soil.
- Since *Rhizoctonia* was the most virulent of the fungi, studies were undertaken to determine its response under a wide range of conditions:
    - *Rhizoctonia* caused seedling blight in nearly every non-cereal crop and causes stunting in crops not otherwise affected.
    - Low soil temperatures (below 17.5 °C) reduced its virulence.
    - High levels of infection reduced nodulation in chickpea.
    - Greater seeding depth reduced emergence and survival in infested soil.
    - Damage to seed did not affect seedling survival, but did reduce seed yield.
    - No resistant cultivars were found, but Yuma was slightly, but consistently, less susceptible to seedling blight and root rot than Dwelley.
    - Delay of seeding into June increases the risk of severe seedling blight.

TECHNICAL REPORT

ABSTRACT

Seedling blight and root rot has become a major concern in chickpea production since several virulent isolates were identified from accessions collected in a survey in 1998. Several studies were undertaken to evaluate the efficacy of seed treatment fungicides to control seedling blight and root rot caused by *Pythium*, *Fusarium* and *Rhizoctonia*. Studies were also conducted to determine the impact of *Rhizoctonia solani* on chickpea nodulation and seed yield, to assess the effect of pathogen concentration, soil temperature, seeding depth and seed damage on its virulence and to determine its host range. Seed treatments such as Vitaflo 280, Captan, Crown, Apron Maxx and a Maxim-Apron-Dividend formulation improved seedling emergence and seed yield in the presence of *Rhizoctonia* and *Fusarium* inoculum. Treatments formulated with metalaxyl improved establishment and yield in the presence of *Pythium*. *Rhizoctonia* reduced emergence and vegetative productivity and increased root rot severity as inoculum concentration increased. Almost all prairie crops except cereals were severely affected by *Rhizoctonia*. No resistant chickpea cultivars were found, but Yuma was slightly, but consistently less susceptible than Dwelley. Root rot and shoot infection severity increased with temperature. Normally, shoot productivity in chickpea attained maximum values at 20° C; *Rhizoctonia* inoculum reduced shoot productivity so that maximum growth occurred at 17.5° C. Root rot reduced nodulation as disease severity increased. Seedling emergence and survival declined with increased seeding depth in *Rhizoctonia*-infested soil. Damage to seed did not reduce seedling establishment, but did reduce yield. Fungicide treatment reduced the impact of seed damage, but did not always restore yield to the same level as undamaged seed.

BACKGROUND

Chickpea (*Cicer arietinum* L.) has recently become a very popular alternative crop for the drier areas of the prairies because it is drought tolerant and has an upright growth habit that is compatible with existing harvesting equipment. It is a valuable addition to existing cereal-based crop rotations because it releases nitrogen as residues decompose, and it provides a break in the disease cycle for cereal crops.

Field surveys in Saskatchewan and Alberta in 1998 and 1999 indicated that root disease was a major limiting factor in chickpea production (Wang et al. 1999, Chang et al. 2000). Some of the fields surveyed had severe root disease infestations that resulted in patchy stands (Wang et al., 1999). Live plants were stunted and a wilt-like collapse of the tops occurred above the soil surface. Many of the taproots were girdled with brownish-black lesions near the soil surface.

Since the cost of chickpea seed is high relative to many other crops, optimization of yield depends on achieving target plant populations and sustained plant health through the growing season. Control of seedling blight plays a vital role in achieving target plant population and can be greatly enhanced by an understanding of factors that influence pathogen aggressiveness and seedling resistance. We have previously noted that other soil pathogens have a marked variation in aggressiveness in response to soil temperature (Hwang et al. 2000a and b). Previous experience has indicated that seedling resistance is not only influenced by plant genetics, but by condition of the seed (Hwang et al. ?2000 c and d?)

Pathogens that cause seedling blight are also responsible for root rot infection in older plants (Wellington, 1962). Root rot limits plant vigour and ultimately seed production

by reducing the number of roots available for nutrient and water uptake and for symbiotic nodulation. It can also reduce canopy density and result in lack of uniformity in growth stage. Therefore, where root rot is severe, yield losses are expected to be high (Xi *et al.*, 1995). Control of seed and root rot diseases is a significant way to increase crop production because crops with healthy root systems use fertilizer and water much more efficiently to achieve their maximum yield potential.

Pythium spp., *Fusarium* spp. and *Rhizoctonia solani* were most commonly isolated from rotted chickpea seeds and infected plants. Increases in the population of these pathogens, and associated loss due to disease, are expected as chickpea acreage increases and susceptible crops are grown repeatedly in the same fields. Improved root disease management could enhance the desirability of including chickpea in cropping rotations.

Conditions at the time of seeding play an important role in both germination and susceptibility to seedling disease. Temperature is one of the prime determinants of these factors. Temperature regulates growth rate not only of the seedling, but also of soil pathogens and injury to seed can occur during germination at low temperatures (Yamamoto, 1984) which can reduce germination and result in less vigorous plant growth over the long term. In the field, sowing date has a profound effect on the microenvironment of the germinating seed and seedling (Adam *et al.* 1989; Omer *et al.* 1989). For example, the mean daily temperature in north-central Alberta increases from 6° to 16°C during the planting season and the daylight period increases by about 2.3 hours (3-5 min/day) (Anon. 1999b). Weather conditions at seeding are highly variable; frost can occur into June and substantial snowfalls have occurred as late as the third week

of May. Consequently, chickpea crops are normally seeded into cool soils in western Canada.

The condition of the seed itself also has a marked effect on seedling viability. Lack of seed vigour delays emergence, weakens seedlings and increases susceptibility to disease (Schlub and Schmitthenner, 1978). Moreover, slow emergence may delay critical growth stages and result in lower seed yield. Most seed germination tests are conducted under optimal conditions and the results tend to overestimate germination under adverse field conditions, especially at low soil temperatures (Wellington, 1962). Therefore, seedlots with similar germination in laboratory tests may differ markedly in establishment under adverse field conditions (Duczmal and Minika, 1989). Mechanical damage to seed is one of the primary causes of decreased seedling vigor and results in increased uptake of water and increased leakage of solutes from seeds. Nutrient leakage not only reduces the nutrients available to the seedling, but also triggers the growth of soilborne pathogens (Schroth and Cook, 1964). Damaged seeds have a greater surface area available for attack by these pathogens (Stasz and Hartman 1980).

Producers can optimize the seedling environment by choice of seeding time, seeding depth, and choice of land with respect to crop rotation history. These choices are most effective when combined with fungicidal seed treatments to protect seedlings until they become established. Protectant fungicides, such as thiram, inhibit pathogen attack on seeds, but leave seedlings vulnerable. Systemic fungicides such as Carboxin or Metalaxyl also provide some protection for seedlings (Cook and Zhang 1985). Many of these fungicides are specific to unique pathogen groups, so must be chosen to manage the predominant pathogens in the area where the crop is being grown.

OBJECTIVES

This study was undertaken to:

1) determine the impact of pythium, rhizoctonia and fusarium seedling blight and root rot on the seed yield of chickpea
2) evaluate the efficacy of seed treatment fungicides to control seedling blight and root rot caused by *Pythium*, *Rhizoctonia* and *Fusarium* spp.
3) determine the pathogenicity/aggressiveness of isolates that occur on chickpea seedlings
4) determine the impact of *Rhizoctonia* on nodulation of chickpea
5) determine the influence of temperature on the aggressiveness and development of rhizoctonia root rot
6) elucidate the role of seeding depth and seed damage in seed and seedling infection and to examine the interaction of seed damage and fungicide seed treatments on seedling establishment and seed yield of chickpea
7) compare available cultivars for susceptibility to Rhizoctonia root rot
8) examine the effect of seeding date and *Rhizoctonia* spp. on seedling establishment and seed yield of field pea

MATERIALS AND METHODS

Controlled environment studies

All controlled environment studies were conducted in 13-cm-diameter fibre pots containing a steam-pasteurized (70 °C for 2 h) mixture of loam, sand and vermiculite (3:1:1, v/v). Chickpea seed was surface-disinfested in 70% ethanol for 2 min, followed by 2 min in 0.6% sodium hypochlorite, then rinsed three times in distilled water. Seeds were planted 2 cm deep in each pot unless otherwise specified. All pots were arranged randomly in a controlled environment growth chamber at 20 °C (16 h day) and 10 °C (8 h night) unless otherwise specified. Changes in air temperature from the nightly minimum to the daily maximum were programmed to occur at a rate of 2 $°C.h^{-1}$. A light intensity of 300 $\mu E.m^{-2}s^{-1}$ was provided by cool-white fluorescent tubes and incandescent bulbs. Pots were watered as necessary with distilled water.

Severity ratings for root rot were assigned on a scale of 0 to 4 where 0 = healthy; 1 = small, light brown lesion on < 25% side of tap root; 2 = brown lesion on 25 - 49% side of tap root; 3 = brown lesion on 50 - 74% side of tap root and tap root constricted; and 4 = tap root extensively girdled with brown lesion on 75 - 100% side of tap root, limited lateral roots present, and plants wilted and stunted or dead.

Fungal isolation and pathogenicity studies. Roots and stem bases bearing distinct lesions were washed thoroughly in running tapwater and cut into 2 x 2 mm pieces. Ten pieces of discoloured root tissue from each of 50 plants were surface-disinfested with 0.6% sodium hypochlorite (v/v) for 1 min, rinsed in sterile distilled water, and plated on pentachloronitrobenzene (PCNB) medium (Nash & Snyder 1962), potato dextrose agar

acidified with lactic acid to pH 5.0 (APDA) or water agar. Single-spore transfers were made from the subcultures of representative *Fusarium* colonies onto fresh PDA tubes and carnation leaf agar plates for species identification according to Nelson et al. (1983). Hyphal tips of *Pythium* and *Rhizoctonia* mycelia growing from root tissue were transferred onto cornmeal agar and representative cultures were identified.

Mycelial inoculum for each test isolate was prepared in 250-mL erlenmeyer flasks containing 100 mL of sterile potato dextrose (PD) broth. The PD broth was inoculated with a 9-mm-diameter mycelial agar disc from a 7-day-old culture and shaken continuously at 200 rpm for seven days at room temperature (20 °C) in natural light. The culture of each flask was comminuted for 15 sec in a Waring blender. Twenty mL of the inoculum of each isolate were poured over the pots containing a steam-pasteurized soil mixture. Noninoculated PD broth was used as a control. For *Rhizoctonia*, a 6-mm-dia. agar disk was taken from 4-day-old cultures of each *R. solani* isolate and grown in a 9-cm petri dish on 20% V-8 juice agar for 10 days. Inoculum of each isolate was prepared by comminuting each dish of fungal culture with 200 ml of distilled water for 15 sec in a Waring blender. Noninoculated V-8 juice agar was used as a control. Surface-disinfested seeds of chickpea cultivar Sanford (Kabuli type) were planted (15 seeds/pot) in each of eight replicate pots. After sowing, both inoculated and control pots were topped with 2 cm of the pasteurized mixture. All pots were randomized in a growth chamber. Percent seedling survival was recorded two weeks after seeding. Shoot and root dry weights (dried at 70 °C for 24 h) were determined three weeks after seeding. Reisolations were made from the roots of diseased plants to confirm pathogenicity of the isolates used to inoculate the plants.

Evaluation of control of *Pythium*

Growth Cabinet Studies

Seed of Kabuli-type chickpea cv. UC-27 and Desi-type chickpea cv. Marengo was treated with Apron (metalaxyl 317 g/L SN) at 0.16 and 0.32 mL/kg seed, Crown (carbathiin 92 g/L + thiabendazole 58 g/L FL, UBI 2521) at 3.0 and 6.0 with Apron at 0.16 mL/kg seed, and Vitaflo 280 at 3.3 mL/kg seed alone and with Apron at 0.16 mL/kg seed. Untreated pots with and without inoculum served as controls.

Field studies

In 1996 and 1997, Chickpea cv. Marango (Desi type) and cv. UC27 (Kabuli type) were treated with Apron at 0.16 mL/kg seed alone, at a double dosage (0.32 mL/kg seed), and with Crown at 3 and 6 mL/kg seed. In 1998, the seed treatments Vitaflo 280 at 3.3 mL/kg alone and added to Apron at 0.16 mL/kg seed were added to the previous treatments. Untreated seed was used as a control at all locations and sown with and without the *Pythium* inoculum.

Field plot experiments were established at two sites, Vegreville and Brooks, Alberta in the spring of 1996 and 1997, and at Brooks in the spring of 1998. Seeds were planted 4 cm deep on May 21 and May 23, 1996 and May 23 and May 28, 1997 at Brooks and Vegreville, respectively and on May 15, 1998 at Brooks, using 40 seeds/row in 1996 and 50 seeds/row in 1997 and 1998. *Pythium ultimum* and *P. irregulare* inoculum was mixed and incorporated with the seed at the rate of 40 mL/row. Each plot consisted of four, 6 m rows at Brooks and four, 4 m rows at Vegreville, with 25 cm

between rows. Adjacent plots were separated by 0.4 m and replicate plots by 2 m. The experiment was arranged in a randomized complete block with four replicates. Seedling emergence was counted three weeks after seeding. Each row in every subplot was counted at both experimental locations. Chickpeas were harvested in Brooks on October 15, 1996, Sept. 25, 1997, and Aug. 24, 1998. In Vegreville, the plots were destroyed by Ascochyta foliar blight years and could not be harvested.

In 1999, chickpea cv. B-90 was treated in a Hege small batch seed treater with Apron XL (metalaxyl-M 369 g ai/L LS and Apron Maxx (metalaxyl-M, 13.6%+fludioxonil, 9.11% MEC) at 3.75 and 7.5 g ai/100 kg seed, Maxim alone (fludioxonil 480g/L FS) at 2.5 g ai/ 100 kg seed and combined with Apron XL at 3.75 and 7.5 g ai/100 kg seed, a combination of Maxim, Apron, and Dividend at 2.5, 7.5 and 12 g ai/100 kg seed, respectively (MAD), alone and combined with Adage at 25 and 50 g ai/100 kg seed as well as with Helix Green (thiamethoxam, 156 g/L FS) at 200 g ai/100 kg seed. Seed was also treated with Vitaflo 280 (carbathiin 14.9%, thiram 13.2% SU) at 88 g ai/100 kg seed. An experimental plot was established on 25 May, 1999 at Brooks, Alberta, in brown chernozemic clay loam soil. The plot was seeded in a randomized complete block design with four replications. Each subplot consisted of four, 6 m rows spaced 30 cm apart. Seeds were planted 5 cm deep at a rate of 75 per row. *Pythium ultimum* and *P. irregulare* inocula were mixed and incorporated at the time of seeding at the rate of 40 mL/row (5×10^2 CFU/mL). Nontreated seeds were planted as inoculated and noninoculated controls All emerged seedlings were counted 3 weeks after seeding. At maturity (October 9), plants were harvested by small plot combine and seeds were weighed to determine yields.

In 2000, seed of chickpea cv. B-90 was treated as described above with Apron Maxx at 3.75 g ai/100 kg seed, a combination of Maxim and Apron XL at 2.5 and 3.75 g ai/100 kg seed, MAD at 22 g ai/100 kg seed, alone and combined with Cruiser at 50 g ai/100 kg seed. Seed was also treated with Vitaflo 280 at 88 g ai/100 kg seed. An experimental plot was established on 18 May, 2000 at Brooks, Alberta using the experimental design described above. *Pythium ultimum* and *P. irregulare* inocula were incorporated at the time of seeding at the rate of 30 mL/row (3×10^2 CFU/mL). Emerged seedlings were counted 4 weeks after seeding. At maturity (27 September), plants were harvested by small plot combine. Seeds were weighed to determine yields.

Evaluation of control of *Fusarium*

Controlled Environment Studies - Seed of Desi-type chickpea cv. Tyson was treated with Apron at 0.16 mL/kg seed. Apron was also added to Crown at 3.0 and 6.0 mL/kg seed and Vitaflo 280 at 3.3 mL/kg seed. Percent seedling survival was evaluated 2 weeks after planting. Shoot and root dry weight was measured 4 weeks after planting. Root rot was also rated at the same time using the previously mentioned rating system.

Field Studies - In 1997 and 1998, Desi type chickpea cv. Tyson was treated with Apron at 0.16 mL/kg seed alone and added to Crown at 3.0 and 6.0 mL/kg seed. Untreated seed with and without *Fusarium* inoculum served as controls. Field plots were established on June 2 and May 29, 1997 at Brooks and Vegreville, respectively and on May 14, 1998 at Brooks. Seeds were planted 4 cm deep, using 50 seeds/row. Each plot consisted of two, 6 m rows at Brooks, and four, 4 m rows at Vegreville, with a 25 cm row spacing. The

experiment was arranged in a randomized complete block with four replicates. Inoculum was incorporated with the seed at a rate of 20 mL/row. Seedling emergence was counted three weeks after seeding. Chickpeas were harvested in Brooks on Sept. 25, 1997 and Aug. 24, 1998. In Vegreville, the plots were destroyed by Ascochyta foliar blight and could not be harvested.

In 1999, seed of chickpea cv. B-90 was treated with the same treatments used in the 1999 *Pythium* experiment and seeded in an experimental plot established on 25 May, 1999 at Brooks, Alberta using the previously described experimental design. *Fusarium avenaceum* inoculum was incorporated at the time of seeding at the rate of 20 mL/row (2.5×10^2 CFU/mL). All emerged seedlings were counted 3 weeks after seeding. At maturity (October 9), plants were harvested by small plot combine and seeds were weighed to determine yields.

In 2000, seed of chickpea cv. B-90 was treated with the same treatments used in the 2000 *Pythium* experiment and seeded in an experimental plot established on 18 May, 2000 at Brooks, Alberta using the previously described experimental design. *Fusarium avenaceum* inoculum was incorporated at the time of seeding at the rate of 30 mL/row (3×10^2 CFU/mL). Emerged seedlings were counted 3 weeks after seeding. At maturity (26 September), plants were harvested by small plot combine and seeds were weighed to determine yields.

Etiology and control of *Rhizoctonia*

Growth Cabinet Studies –

Inoculum density

The population density of *R. solani* isolate CKPR-1, was adjusted by adding the infested cornmeal-sand inoculum to steam-pasteurised soil mixture in ratios of 1:50, 1:100, 1:200, 1:500 and 1:1000 (w/w). The soil mixture and inoculum were mixed in a twin-shell blender for 1 h, then immediately potted. The ratios resulted in inoculum densities between 4×10^4 and 0.2×10^4 cfu/g of soil mixture. This isolate had been shown to be highly aggressive on chickpea seedlings in the pathogenicity trials (described above). Pasteurised soil mixture treated with noninfested cornmeal-sand inoculum (1:200, w/w) was used as the control. Ten pots (replicates) of cv. Sanford were planted per treatment and arranged in a randomised complete block design. Percent stand counts were made at regular intervals over 26 days after planting. Shoot and root dry weights per pot were recorded 1 month after seeding. The experiment was repeated using cv. Tyson. The response of the two cultivars was very similar, so the data were pooled for analysis and presentation.

Soil temperature (gradient plate)

The effect of temperature on infection of chickpea seedlings was studied using a temperature gradient plate (McLaughlin *et al.* 1985) to simulate diurnal soil temperature fluctuations. Temperatures in each cell of the gradient plate are independent of adjacent cells. The temperature combinations (°C day/night, 12-hr photoperiod under fluorescent light with 107 $\mu E\ m^{-2}\ s^{-1}$ at plant height) were:10°/5°, 15°/5°, 15°/10°, 20°/5°, 20°/10°, 20°/15°, 25°/10°, 25°/15°, 25°/20°, 30°/15°, 30°/20°, and 35°/20°C. Two isolates, one

each of *R. solani* (CKPR-1) was assessed in the trial. The trial was laid out in a split-plot design, with isolates as main plots and temperatures as subplots. Each subplot consisted of a cluster of four cells on the gradient plate. Each cell held an 8-cm deep, 10 cm dia. glass petri dish containing 100 ml of 1.5% water agar. Seed of cvs. Sanford and Tyson was soaked overnight and then surface sterilized in 0.6% NaOCl for 5 min. Four germinating seeds were placed on the agar in each dish. A plug of inoculum was placed in the centre of each of three dishes; the remaining dish was a noninoculated control. After 8 to 9 days, the dishes were removed from the gradient plate. Root rot severity was assessed on a 4-point scale (0 = no symptoms, 1 = 1-25% of the root infected, 2 = 26-50% of the root infected, 3 = 51-100% of the root infected), infection of shoots was assessed (0 = no symptoms, 1 = infected) and the height of each seedling was measured. The test was conducted twice, and the data were pooled for analysis.

Soil temperature (growth cabinet)

The impact of soil temperature and inoculation on seedling emergence and growth rate was examined in a study conducted in a factorial randomized complete block design. Three soil temperature regimes were assessed: 12°/1°, 17°/3°, and 21°/8°C (day/night temperatures, with a 12-hr photoperiod under fluorescent lights at 300-400 $\mu E\ m^{-2}\ s^{-1}$). The other factor was inoculation with *R. solani* (isolate CKPR-1) versus an noninoculated control. Ten seeds of cv. Sanford and Tyson were planted at 2-cm depth in each pot (13-cm dia., filled with soilless mix), with 12 pots per treatment, arranged randomly in a growth chamber. Percent stand counts were made at 6 intervals over 17 days after planting and results were expressed as percentages. The experiment was terminated one month after seeding and

shoot and root dry weights per pot were recorded. The experiment was conducted twice and the data were pooled for analysis.

Effect of root rot on nodulation. Seed of Stanford chickpea was treated with peat-based *Rhizobium leguminosarum* F. (Enfix-L^{TM}), having a population of 4 x 10^8 cells/g air dry peat, at the rate of 0.4 g/100 g seed. To obtain chickpea seedlings with different root rot severities, the rhizobia-treated seed was sown immediately in root trainers containing soil infested with different inoculum densities as described earlier. The experimental design was a randomized complete block with four replications. Each trainer in each block was treated as an experimental unit with 32 root cells and one seedling per cell. Four weeks later, the root system of each plant was washed, blotted dry with paper towels, and separated into five categories based on root rot severity ratings. Fifty plants were selected at random from each disease severity category, and the level of nodulation and fresh weight of nodules per root system were determined. The experiment was repeated using seed of Tyson Chickpea.

Effect of seeding depth. Seed of Stanford chickpea was planted in pots containing infested or noninfested soil mixture. There were 10 seeds per pot and 10 replicate pots per treatment. A 2 x 2 factorial design was used, with pots filled with infested (2 x 10^4 cfu/g) or noninfested soil mixture as one factor and two depths of seeding (2 or 5 cm) as the other factor. The experiment was repeated using Tyson chickpea. Percent seedling emergence was recorded one week after seeding. Percent seedling survival, root rot severity, and shoot and root dry weights were measured four weeks after seeding.

Host Range Alfalfa, barley, canola, chickpea, red and alsike clover, white and black dry bean, flax, lentil, oats, pea, soybean and red spring and durum wheat were assessed for susceptibility to seedling damping-off due to *Rhizoctonia* isolates CKPR-1 and CKPR-3. Cultivars are listed in Table 16. Seed of each cultivar was planted in pots containing infested or noninfested soil mixture and grown at 25° C with a 12 h light/dark cycle in a greenhouse. There were 10 seeds per pot and 10 replicate pots per treatment. Percent seedling survival, plant height and shoot weight and root rot severity were measured four weeks after seeding.

Field Studies

Fungicide seed treatment-

- 1999

In 1999, efficacy tests of fungicide seed treatments U2727, LO176, [Apron (metalaxyl at 0.6 mL a.i. per kg seed), Vitaflo 280 (carbathiin + thiram at 3.3 mL a.i.) and Apron at 0.3mL + Vitaflo at 1.9 mL a.i.] were conducted at Brooks AB. The fungicides were applied to seed of chickpea pea cvs. Sanford and Tyson in a large Erlenmeyer flask. Nontreated seed was used as a control. The treatments were arranged in a randomized split plot design with four replications. The two cultivars served as main plots and fungicide treatments, along with *Rhizoctonia*-inoculated and non-inoculated controls served as subplots. Each subplot consisted of four rows, 6 m in length, with a 0.25 m inter-row spacing and 75 seeds per row. Adjacent plots were separated by 0.6 m, with 2 m between replicates. Inoculum of *R. solani* (CKPR-1) was applied with the seed at 30 mL /row. Emerged seedlings were counted for each subplot three weeks (June 18) after seeding along 6 m lengths of the two middle rows of each plot. At maturity (October 11), the plots were harvested and seed yield was determined.

Fungicide seed treatment - 2000A

Seed of chickpea cvs. Myles and Sanford was treated with Vitaflo 280 at 3.3 mL/kg seed, Crown at 3.0 and 6.0 mL/kg seed and a combination of LS 176 and Apron FL at 3.1 and 0.16 mL/kg seed, respectively, in a Hege II small batch seed treater. Experimental plots were established on 18 May, 2000 at Brooks, Alberta using the same experimental design as above. Emerged seedlings were counted for each subplot three weeks after seeding. At maturity (26 September), plants from the middle 5 m of each plot were hand-harvested. Seeds were threshed and weighed to determine yields.

Fungicide seed treatment - 2000B

Seed of chickpea cvs. Myles and Sanford was treated with Vitaflo 280 at 2.6 and 3.3 mL/kg seed, Vitaflo + Apron at 2.6 and 0.16 mL/kg seed, respectively, Captan at 2.1 mL/kg seed and a combination of LS 176 and Apron FL at 3.1 and 0.16 mL/kg seed, respectively, in a Hege II small batch seed treater. Experimental plots were established on 24 May, 2000 at Saskatoon, Saskatchewan using the same experimental design as above. Emerged seedlings were counted for each subplot three weeks after seeding. At maturity (11 October), plants from the middle 5 m of each plot were harvested by small plot combine. Roots of 25 plants from each sub-plot were sampled and rated for root rot severity. Seeds were threshed and weighed to determine yields.

Fungicide seed treatment – 2000C

Seed of chickpea cv. B-90 was treated in a Hege small batch seed treater as in the 2000 *Pythium* and *Fusarium* experiments. An experimental plot was established on

18 May, 2000 at Brooks, Alberta with the same experimental design as these experiments. Emerged seedlings were counted 4 weeks after seeding. At maturity (27 September), plants were harvested by small plot combine. Seeds were weighed to determine yields.

Fungicide seed treatment – 2001A

MATERIALS: L0020 (metalaxyl, 320 g/L FL), L1022 (metalaxyl 12 g/L + ipconazole, 7.5 g/L RTU), U2521 (carbathiin, 90 g/L + TBZ, 58 g/L FS), L1030 (HEC 5725, 100 g/L SU), L1031 (HEC 5725, 37.5 g/L + triazolinthion, 37.5 g/L SU), U2051 (carbathiin, 170 g/L + thiram, 150 g/L SU), L0202 (carbathiin, 100 g/L + thiram, 100 g/L + metalaxyl, 16.2 g/L SU).

Seed of chickpea cv. Dwelley was treated in a Hege II small batch seed treater with L1022 at 3.1 mL/kg seed, L0202 at 4.4 mL/kg seed and with L0020 at 0.16 mL/kg seed, either alone or in combination with U2521 at 3.0 or 4.5 mL/kg seed, U2051 at 3.3 mL/kg seed, L1030 at 1.0 mL/kg seed, or with L1031 at 1.33 mL/kg seed. Experimental plots were established on 20 May at Brooks, Alberta in brown chernozemic clay loam soil. Plots were seeded in a randomized complete block design with four replications. *Rhizoctonia*-inoculated and non-inoculated controls were seeded along with the treatments. Each subplot consisted of four, 6 m rows of plants spaced 30 cm apart. Seeds were planted 5 cm deep at a rate of 75 seeds per row. *Rhizoctonia solani* was grown on a mixture of sterilized oat and rye kernels for 14 days, dried, ground and incorporated as inoculum at the rate of 25 mL/row at the time of seeding. Emerged seedlings were counted for each subplot on 18 June. At maturity (24 September), plots were harvested by small-plot combine. Seeds were weighed to determine yields.

Fungicide seed treatment – 2001B

MATERIALS: Crown (carbathiin, 92 g/L + TBZ, 58 g/L SU), Apron Maxx 240.5 (metalaxyl-M 13.6% + fludioxonil 9.11% MEC)

Seed of chickpea cv. B-90 was treated in a Hege small batch seed treater with Apron Maxx at 6.25 or 12.5 g ai/100 kg seed, or with Crown at 90.0 g ai/100 kg seed. An experimental plot was established on 15 May, 2001 at Brooks, Alberta, in brown chernozemic clay loam soil. The plot was seeded in a randomized complete block design with four replications. Each subplot consisted of four, 6 m rows of plants spaced 30 cm apart. Seeds were planted 5 cm deep at a rate of 75 seeds per row. *Rhizoctonia solani* was grown on sterilized oat grains for 14 days, dried, ground, and incorporated at the time of seeding at the rate of 30 mL/row (3×10^2 cfu/mL). Nontreated seeds were planted as inoculated and noninoculated controls. Emerged seedlings were counted on 11 June. At maturity (17 September), plants were harvested by small plot combine. Seeds were weighed to determine yields.

Seed damage

Field trials with four replications in a split-split-plot design were established at Brooks, AB on 26 May 1999 and on 17 May 2000. The main plot treatments were inoculated vs. noninoculated (*Rhizoctonia*-infected grain vs. sterile grain), the sub-plots were sown with seed treated with Vitaflo 280 or left untreated, and the sub-sub-plots were either damaged or nondamaged seed of chickpea cvs. Sanford, Tyson or B-90. Drop damage was produced by freezing the seed at –30 °C, then dropping it 4 m onto a concrete floor. Damaged and nondamaged portions of the seedlots were treated in a Hege II small batch seed treater with Apron (metalaxyl 317 g/L SN)+VITAFLO 280

(carbathiin 14.9% + thiram 13.2% SU) at the rates given in Table 1, or left untreated as a control. Each sub-sub-plot consisted of 4 rows, each 6 m long and spaced 25 cm apart. Seeds were planted 5cm deep with a v-belt seeder at 75 seeds/row. Inoculum (30 ml/row) was planted with the seed. Seedlings were counted in 5m lengths of the two middle rows of each plot 3 wk after seeding. Plots were harvested on 9 October, 1999 and 27 September, 2000 and seed yield was determined.

Cultivar Comparisons

Seven chickpea cultivars, Myles, Tyson, Yuma, B-90, Xena, Sanford, and Dwelley, were planted into experimental plots at Brooks, Alberta on 26 May, 1999 and on 18 May, 2000. Plots were seeded as described previously in a randomized complete block design. *Rhizoctonia solani* inoculum was incorporated into plots with the seed at the time of seeding.

Seeding Date

Field plots were seeded to determine the effects of seeding date on the development of rhizoctonia root rot at Brooks, AB on May 19, 29 and June 7, 2000 and on May 9, May 23 and June 1, 2001. Plots were seeded at Saskatoon, SK on May 5, 17 and June 1, 2000. The experiments were set up in a randomized split plot design with four replications. *Rhizoctonia solani* inoculum or sterile grain (30 mL/row) was sown with the seed in main plots, and seeding date constituted the sub-plots. Subplots consisted of four, 6m rows with a 0.2 m inter-row spacing seeded with 75 seeds/row. Adjacent plots were separated by 0.6 m, with 2 m between replicates. Emerged seedlings were counted 3 wk after seeding Counting June 11, 2001 and seed yields were determined after harvesting on

September 26 and October 11, 2000 at Brooks and Saskatoon, respectively and on September 24, 2001 at Brooks. When the plants were mature, 25 plants were sampled from each plot, washed, and assessed for root rot severity at Saskatoon.

Statistical Analysis

Data were subjected to an analysis of variance using a General Linear Models Procedure and means were compared using Duncan's New Multiple Range test at $P \leq 0.05$ of significance on SAS software (SAS Inst. Inc. 1985). Bartlett's test showed that variances were homogeneous for the different years and thus data were combined and analyzed using date of planting as a third factor.

In the inoculum density study, percentage data were arcsine transformed before analysis to improve homogeneity of variance. Analysis was performed on transformed plant survival data for each cultivar. To compare the inoculum density for each cultivar, a transformation [ln(square root)] was applied to inoculum density values to linearize the relationship with percentage seedling survival. Linear regression analysis was used to summarise the effect of inoculum density on shoot and root dry weight.

RESULTS

Fungal isolation and pathogenicity. Eleven isolates of *Pythium*, twelve isolates of *Fusarium* and five isolates of *Rhizoctonia* were obtained from diseased chickpea plants collected from fields in southern Alberta and west-central Saskatchewan (Tables 1 and 2). The *Fusarium* isolates were grouped according to similar morphological characteristics of mycelium and spores, and representative cultures were identified (Table 1). In total, three *Fusarium* species were identified: *F. oxysporum*, *F. avenaceum*, and *F. solani*, in a ratio of 1:1:2, respectively. *F. avenaceum* was the most virulent, and killed nearly every seedling.

Both *F. oxysporum* and *F. solani* produced superficial brownish discoloration on roots of both cultivars. However, only the symptoms caused by *F. avenaceum* on chickpea in the growth chamber tests were similar to those observed on diseased plants in the field. The taproots were girdled, plants became stunted, and finally complete wilt-like collapse of the plants occurred at or slightly below the soil surface. All *F. avenaceum* isolates tested were pathogenic to chickpea (Table 1). Differences in aggressiveness were observed among isolates of *F. avenaceum* on chickpea. Control plants remained symptomless and *F. avenaceum* was consistently reisolated from diseased tissue, thus completing Koch's postulates.

Four of the *Pythium* isolates, KP-2, 3, 5 and 10, reduced seedling emergence. These isolates and KP-9 also reduced shoot and root dry matter yield. All of the isolates caused root rot symptoms (Table 2). All of the *Rhizoctonia* isolates killed every seedling (Table 1).

Chemical Control of *Pythium* Root Rot

Under controlled environment conditions, germination of nontreated seed and seed treated with Vitaflo 280 was nil for the Kabuli-type chickpea and almost completely suppressed for the Desi type (Table 3). All Apron treatments resulted in significantly higher survival and biomass and lower root rot severity than treatments without Apron. Noninoculated treatments had significantly greater plant survival and biomass and lower root rot severity than all inoculated treatments. Apron applied at double dosage did not significantly change survival, productivity or root rot compared with application at the normal rate (0.16 mL/kg seed), in most cases. In most cases, Crown applied at double dosage resulted in lower survival and biomass productivity than where applied at the normal dosage (3.0 mL/kg seed) or where not applied. Most treatments that included Apron had no significant difference in survival, root rot, or biomass productivity between them.

Under field conditions in 1996 and 1997, the Kabuli type of chickpea was more susceptible to *Pythium* than the Desi type. Natural inoculum resulted in seedling losses in all nontreated plots except for the Desi-type plots at Brooks (Table 4). Treatment with Apron substantially improved seedling emergence for the Kabuli type and resulted in greater seed yield than in nontreated plots at the Brooks site. Treatment with Apron significantly increased seedling numbers in the Desi type chickpea at the Vegreville site. There was no significant difference between Apron dosage rates with respect to number of seedlings and yield.

Treatments including Vitaflo 280 were added in 1998, but did not significantly improve seedling emergence or seed yield when Apron was not present (Table 5).

Application of Apron at a double dosage did not improve seedling emergence or seed yield over the normal dosage. There was no difference between Apron treatments with respect to seed yield, but treatments which included Crown resulted in lower seedling emergence than in noninoculated plots, while Apron treatments without Crown had seedling emergence comparable to noninoculated plots.

1999 - All seed treatments in the trial, except Maxim alone, significantly increased seedling emergence over the inoculated control (Table 6). The Apron, Apron Maxx and Maxim-Apron combinations significantly improved emergence over both inoculated and noninoculated controls, over Maxim and over Vitaflo 280. Seed yield was significantly improved over the inoculated control by Apron XL at the higher rate, Apron Maxx at both rates, and by all Maxim-Apron-Dividend combinations, except where Adage was included at the higher rate. Apron Maxx at the lower rate and the Maxim-Apron-Dividend combination alone, or in combination with Helix Green, also significantly improved seed yield over Vitaflo 280 and Maxim alone.

2000 -Seedling emergence in both inoculated and noninoculated controls was significantly lower than in any of the fungicidal seed treatments (Table 7). Among the treatments tested, Vitaflo 280 resulted in the poorest emergence, which was significantly lower than Apron or any of the MAD formulations but there were no differences with respect to yield.

Chemical Control of *Fusarium* Root Rot

Under controlled environmental conditions, seed treated with Apron plus Crown at the higher rate or Vitaflo 280 showed greater survival and vegetative productivity and lower root rot severity than seed treated with Apron plus Crown at the lower rate, or with Apron alone, or left untreated (Table 8). In the field, all fungicidal treatments significantly improved seedling emergence and yield relative to the *Fusarium* treatment (Table 9). Seed treated with Crown also resulted in significantly greater yield than in noninoculated plots, but seed treated with Apron alone did not.

1999 - All seed treatments in the trial except Apron XL at the higher rate significantly increased emergence over the inoculated control Table 10. Combinations including Maxim or Apron Maxx all produced significantly greater emergence than Apron XL, Vitaflo 280 or Maxim alone. All treatments except the two rates of Apron XL showed higher seed yield than the inoculated or noninoculated controls. Treatments where Adage or Helix Green were included in the formulation had significantly higher seed yields than those without, except for Apron Maxx at the higher rate.

2000 - All treatments in the trial produced significantly higher seedling emergence and seed yield than the inoculated control, and all treatments except Vitaflo 280 had higher seedling emergence than the noninoculated control (Table 11). There were no significant differences in emergence or seed yield among the five chemical treatments.

Etiology and control of *Rhizoctonia*

Inoculum density

Infection by *R. solani* occurred at all inoculum densities. Seedling survival and shoot height and root dry weight declined and the root rot index increased as inoculum concentration increased ($P \leq 0.01$); this relationship remained quite constant over the course of the experiment for both chickpea cultivars (Fig. 1). The R^2 values for both cultivars were significant ($P \leq 0.05$). Reduction in survival, shoot height and root dry weight and increase in root rot with increased inoculum density was more pronounced for Sanford than for Tyson (Fig. 1).

Soil temperature (gradient plate)

Temperature had a substantial impact on infection of chickpea seedlings by *Rhizoctonia* spp. in this experiment. For cv. Sanford, root rot severity was low at a mean daily temperature of 7.5 °C, but rapidly increased with temperature and reached the maximum value at mean daily temperatures of 15 °C and above (Table 12). For cv. Tyson root rot severity increased more gradually as the mean daily temperature increased and reached the maximum value at 27.5 °C. At the same mean daily temperature, root rot was generally slightly, but not significantly, more severe where the daytime temperature was higher. Shoot infection was nonexistent at 7.5 °C, but increased to the maximum value where mean daily temperature exceeded 17.5 °C for Sanford and 22.5 °C for Tyson. In noninoculated cells, shoot height peaked at 20 °C for Sanford and 22.5 °C for Tyson, although growth of Tyson was similar across the entire range of temperatures and differences were significant for Sanford were significant only between 20 °C and the

lowest temperature in the trial. Inoculation substantially reduced seedling height for Sanford chickpea but had a much smaller impact on seedling height for Tyson chickpea (Table 12).

Soil temperature (growth cabinets)

Emergence was unaffected by temperature for cv. Sanford where no inoculum was applied, but low inoculum pressure produced a substantial drop in emergence at low temperatures and high inoculum pressure reduced emergence at both low and high temperatures, but left the intermediate temperature regime unaffected (Table 13). Emergence for Tyson fell slightly with temperature where no inoculum was applied. Inoculum pressure produced a slight drop in emergence at the higher temperature, did not affect emergence at the intermediate temperature, and produced a sharp drop in emergence at the lower temperature. Shoot height increased with temperature, regardless of inoculation for cv. Tyson, and for cv. Sanford without inoculum, or at low inoculum concentration. However at the high inoculum concentration, shoot height for this cultivar was markedly reduced at both high and low temperatures and remained relatively unaffected at the intermediate temperature. Root rot severity increased with temperature for inoculated treatments of cv. Tyson, but for cv. Sanford, root rot was generally less severe at the intermediate temperature and more severe at the low temperature. Under high inoculum pressure, however, root rot was severe at both lower and higher temperatures.

Effect of root rot on nodulation. All levels of root rot severity significantly reduced nodulation compared with healthy plants, for both Sanford and Tyson (Table 14). Root rot

levels 1 and 2 resulted in similar nodulation, but nodulation was reduced significantly for both cultivars at each of the subsequent levels. For Sanford chickpeas, all levels of root rot reduced root dry weight, but for Tyson, root dry weighs for levels 1 and 2 were similar to those of healthy plants. Root rot levels 3 and 4 resulted in significant reductions in root dry weight from the previous level for Tyson, but for Sanford, level 3 resulted in significantly lower root dry weights than level 1, but root dry weights were not significantly lower than level 2. The greatest decreases in nodule number and root dry weight occurred at disease severity levels of 3 and 4.

Effect of seeding depth. Percent seedling emergence and survival, and shoot and root dry weights of both chickpea cultivars at both seeding depths in infested soil were less than those of plants in uninfested soil (Table 15). In noninfested soil, both shoot and root dry weight of both chickpea cultivars was similar regardless of seeding depth. In infested soil, root dry weight was also similar for both seedling depths, but shoot dry weight was lower for the greater seeding depth for both cultivars. Emergence was lower and root rot was more severe at the greater planting depth.

Host Range

Host susceptibility data are presented in Table 16. The *Rhizoctonia* isolates caused severe seedling damping-off in canola, chickpea, red and alsike clover, flax, lentil, pea and durum wheat. Barley, dry bean, soybean, oats and red spring wheat were relatively unaffected by seedling damping-off due to these isolates. Alfalfa cv. Algonquin was severely affected by the pathogen while cv. Peace was not. Most cultivars, including those not susceptible to damping-off, were affected by root rot in inoculated treatments. Plants in

cultivars that were affected by damping-off were shorter than plants grown in noninoculated soil. Barley cv. Lacombe, and all of the dry bean cultivars except the black cultivar U1906 also showed reduced growth, despite lack of susceptibility to damping-off. Some of the cereals showed lesions on the first leaves.

Fungicidal seed treatment

- 1999

Vitaflo and U2727 significantly ($P \leq 0.05$) improved seedling emergence and seed yield over the inoculated control (Table 17). Vitaflo improved seedling emergence over the noninoculated control and over all other inoculated treatments and improved seed yield over all treatments except U2727. Sanford and Tyson had similar seedling emergence but Sanford produced a higher seed yield.

- 2000A

Vitaflo + Apron and Crown applied at the higher rate improved plant stand and seed yield over the inoculated control and over LS 176, Crown applied at the lower rate, and Apron applied alone (Table 18). Stand and yield were higher for Myles than for Sanford.

- 2000 B

All seed treatments except LS 176 + metalaxyl improved seedling emergence and seed yield over the inoculated control, however none of the treatments brought seed yield levels up to those found in the noninoculated control (Table 19). Root rot severity did not differ significantly among the treatments. Emergence and root rot levels were similar between the two cultivars, but Myles produced a higher seed yield than Sanford.

- 2000C

Both MAD formulations and Vitaflo 280 improved seedling emergence and seed yield over the inoculated control, while Apron XL + Maxim and Apron Maxx did not (Table 20). Emergence and yield were higher in the noninoculated control than in any of the inoculated treatments.

-2001A

All fungicidal seed treatments significantly ($P \leq 0.05$) improved both emergence and seed yield (Table 21). However, treatment with L0020 alone resulted in less improvement in emergence and yield than the rest of the fungicidal seed treatments. L1022 produced higher emergence levels than L0020 but lower emergence than the rest of the fungicidal seed treatments.

-2001B

Emergence and seed yields were significantly ($P \leq 0.05$) higher for all seed treatments in the trial than for the inoculated control (Table 22). Emergence and yield were similar among all seed treatments and the noninoculated control.

Seed damage

B-90 and Tyson produced significantly more seedlings than cv. Sanford. Damage to seed did not affect seedling survival, but damage to seeds of cvs. B-90 and Sanford did result in a lower seed yield compared to undamaged seed (Table 23). Inoculation with *Rhizoctonia* reduced seedling survival and seed yield and treatment with Vitaflo + Apron improved both seedling survival and seed yield.

Cultivar Trials

Under greenhouse conditions, Sanford, Xena and Yuma had significantly greater seedling survival than Myles or Tyson (Table 24). These three cultivars and B-90 also had the lowest root rot ratings, while Myles and Tyson had the highest. Xena and Yuma also produced the highest shoot and root dry weights. Under field conditions, Yuma was the most resistant to *Rhizoctonia* seedling damping-off in 1999 and 2001, but Myles was the most resistant in 2000 (Table 25). Dwelley was least resistant in 1999 and 2000, but B-90 was least resistant in 2001. Few seedlings survived in inoculated treatments. No consistent trends were noted among inoculated treatments with respect to yield.

Seeding Date

Inoculation reduced seedling emergence and seed yield both at Brooks in both years and also at Saskatoon, but had little effect on root rot severity (Table 26). Later seeding severely inhibited seedling emergence and seed yield at Brooks in 2000, but early seeding inhibited emergence and yield for cv. Dwelley in 2001. Seedling emergence and seed yield was similar among all three seeding dates at Saskatoon and for cv. Myles at Brooks in 2001. Inoculation and cultivar had no effect on level of root rot severity observed at Saskatoon, but root rot levels were higher for the second seeding date than for the first in cv. Myles.

Discussion

Pythium ultimum, *Fusarium avenaceum* and *Rhizoctonia solani* were isolated from a significant number of fields with chickpea root rot symptoms. Two of the *Fusarium* isolates and all of the *Rhizoctonia* isolates were extremely virulent. Representative isolates of *Rhizoctonia* caused seedling damping-off in a wide range of species under greenhouse conditions. However, chickpea plants showed extraordinary sensitivity to *Pythium* under field conditions, especially when plots were seeded in early spring. In such cases seed had to be amended with metalaxyl in order to obtain any seedling establishment. Chickpea crops can compensate to some degree for unthrifty seedlings, so substantial losses in plant population must occur before yield potential is reduced. Root rotting pathogens not only reduce plant populations at the seedling stage, but also cause injury to the roots that can restrict uptake of water and nutrients. They also attack symbiotic nodules of nitrogen-fixing bacteria. This can result in uneven stands with increased potential for weed invasion and decreased yield potential.

Most field crops that are commonly grown on the prairies showed susceptibility toward *Rhizoctonia*. Cereal crops, dry beans and soybeans generally showed less susceptibility to damping-off than chickpea plants and flax showed more. Different varieties of chickpea exhibited varying degrees of susceptibility and the desi cultivars showed more susceptibility than the kabuli cultivars.

This study showed a great deal of variation in nodule mass from plant to plant. The number and mass of nodules diminished as disease became more severe, and generally reflected the condition of the root itself. Reduced nodulation would likely result in lower

yield and quality of chickpea grain because of reduced nitrogen fixation.

The differential impact of temperature on the relative growth rates of host and pathogen often affects disease severity (Beach 1949; Leach 1947; Bhatti & Kraft 1992). Time to emergence decreases and rate of hypocotyl growth rate increases with temperature in pea (Leath, 1947), flax (O'Connor and Gusta 1994) and winter wheat (Lafond and Fowler 1989). In the gradient plate study, disease development was strongly influenced by temperature. In this study, temperatures above 20 °C resulted in strong suppression of growth where cells were inoculated with *R. solani*. Inoculation by *R. solani* shifted the temperature of maximum growth downward by about 2.5 °C. Treatments with the same mean temperature but different day/night regimes did not produce substantially different results.

In the absence of pathogen inoculation, chickpea seedlings grew more quickly in controlled environment chambers with increased soil temperature. In the presence of *Rhizoctonia*, root rot levels increased with temperature for Tyson, but for Kabuli chickpea, the moderate (17/3 °C) temperatures allowed more seedling growth and less root rot to develop. In this case, the plants were highly sensitive to root rot. High temperatures (averaging 15 °C) permitted complete consumption of the roots by the pathogen, in most cases before a shoot appeared. Low temperatures (averaging 6.5 °C) appeared to encourage root development in the absence of pathogen inoculum, but also increased the sensitivity to the pathogen. The moderate temperature (averaging 10 °C) allowed the roots to resist the pathogen to some degree and to outgrow it. The 12°/1°C and 17°/3° regimes correspond to normal soil temperatures early in May, while 21°/8°C more closely reflects conditions that are common in mid to late May. Warm temperatures following later

planting accelerate seed germination and emergence, but may also favour damping-off caused by *Rhizoctonia solani*.

Soil temperatures influence activity of some diseases incited by *Pythium ultimum*, *Fusarium avenaceum* and *Rhizoctonia solani*. Measurement of soil temperatures at 5-cm depth in our field trials supported the assumption that the 12/6°C regime approximates soil temperatures in the region early in May, while 20/10°C reflects soil temperatures in late May and early June. Since *Rhizoctonia* becomes more active as soil temperatures increase, to be effective, treatments to reduce rhizoctonia injury must protect seedlings for an extended period. *Pythium* sp. are not very competitive, and only grow well where other pathogens are either not present or have greatly reduced activity due to low soil temperature (Hendrix and Campbell 1973). Since chickpea is very sensitive to both *Pythium* and *Rhizoctonia*, the optimum date for planting chickpea crops in Alberta depends on soil temperature. On average, soil temperatures in the last two weeks of May have warmed sufficiently to allow seedlings to outgrow *Pythium*, but have not become warm enough to stimulate activity of *Rhizoctonia*. Temperatures following planting are not usually predictable, so fungicidal seed treatments remain an important component of successful chickpea seedling establishment.

Many of the seed treatments in the field trials mitigated the effects of *Pythium*, *Fusarium* and *Rhizoctonia* but did not completely reverse them. However, where no seed treatment was used, emergence was near zero. Kaiser and Hannan (1983) demonstrated that *Pythium ultimum* was the only fungus pathogenic to chickpeas that was isolated consistently from rotted seeds in controlled inoculation studies. Since metalaxyl provides protection largely against Phycomycetes such as *Pythium* sp., it is probably this

pathogen that is most active and prevalent in the fields at and soon after planting, since metalaxyl treatments were effective in field trials that did not use *Pythium* inoculum as well as in those that did. It is not clear whether the effectiveness of Vitavax is due to the effect of carboxin on *Fusarium* and *Rhizoctonia* or the broad-spectrum thiram, which would also be effective against the previously mentioned *Pythium* sp. The ineffectiveness of benomyl, which theoretically protects against *Fusarium* and *Rhizoctonia*, gives support to thiram being the important component in Vitavax.

Fusarium causes seedling damping off and root rot under warmer and drier conditions. This may reflect the variability of control of seedling damping-off using Crown from site to site and from season to season. Root rot caused by *Pythium* spp. and *Fusarium* may become an important problem as chickpea production is extended northward into areas with more favourable conditions for these pathogens.

Plants inoculated with *Rhizoctonia* responded dramatically to seed treatment. In several cases, there was little or no emergence or yield from the untreated plots, while treatment with Vitaflo 280, Crown, or Apron Maxx restored yield to levels within 50-75% of those observed in the noninoculated control.

The use of systemic fungicides on a large acreage increases the selective pressure towards resistance in pathogens and can threaten the long-term usefulness of these fungicides. Integrating the use of fungicides with high quality seed and early seeding provides a more efficient and reliable agronomic package than any single practice on its own. None of the cultivars tested showed enough resistance to rhizoctonia to warrant its use as an alternative to seed treatment. However, Yuma showed consistently lower susceptibility to root rot than Dwelley, which suggests a genetic basis for resistance to

root rot that could be enhanced through breeding efforts.

Damage caused by rough or repeated handling of seed did not substantially reduce chickpea seedling establishment, but did reduce yield potential when fungicide seed treatment was not utilized, especially in soils that were heavily infested with *Rhizoctonia*. Therefore, only seed lots with high vigor should be used. Seed damage can be reduced by modifications to handling equipment, careful attention to equipment settings and moisture content of seed during harvest. Seeding at shallower depths enhanced seedling survival and shoot productivity and reduced root rot severity in infested soil used in greenhouse trials. However, under field conditions, attention must be given to the moisture level prevalent at the planned seeding depth, since seeds depend on soil moisture to germinate and establish seedlings.

Conclusions

- Inoculation with *Pythium ultimum*, *Fusarium avenaceum* or *Rhizoctonia solani* consistently reduced seedling emergence and establishment, increased root rot severity and reduced seed yield of chickpea.
- Increases in root rot severity were associated with a reduction in the number and size of nodules, which can significantly affect plant development and yield.
- Rhizoctonia root rot has the potential to become an important problem as chickpea production increases in southern Alberta and Saskatchewan, where spring conditions often favour this disease. Where inoculum levels are high, fungicide seed treatment is warranted.

- Consistently higher numbers of seedlings were established from chickpea seed that was treated with Apron in field studies, suggesting that *Pythium* plays a major role in thwarting seedling establishment. This study demonstrated that the most effective method of increasing emergence was to control pre- and post-emergence seed rots caused by *Pythium* spp. through the use of fungicide seed treatments such as Apron.
- Seed treatment with Apron at a high application rate did not result in greater control of seedling blight caused by *Pythium* spp. compared to a low rate of application.
- Although no resistant cultivars were found, Yuma was slightly, but consistently less susceptible to *Rhizoctonia* seedling blight than Dwelley.
- Treatment with Vitaflo 280 or Maxim did not improve seedling emergence or seed yield where *Pythium* inoculum was used in the trial.
- Both Crown and Vitaflo 280, when combined with Apron, provide control of seedling blight and root rot where *Fusarium* was present.
- In field studies with *Rhizoctonia*, Apron Maxx, Crown, Captan, Vitaflo 280 and the Maxim-Apron-Dividend combinations showed the greatest positive impact on seedling emergence.

Implications for Agriculture

Chickpea (*Cicer arietinum* L.) has become a popular crop for the low moisture areas of Saskatchewan and Alberta. Seeded area has increased from zero to more than one million acres over the past five years on the Canadian prairies and the crop shows every indication of becoming a major source of income for prairie farmers. However, field surveys have revealed that many stands were thin and patchy. *Pythium ultimum*, *Fusarium avenaceum* and *Rhizoctonia solani* were commonly isolated from affected plants. In many cases, the level of root disease was sufficient to limit crop productivity.

Root rot has the potential to be an important constraint to chickpea production on the Canadian prairies. *R. solani* can attack a broad range of host plants, causes seedling blight in most non-cereal crops and causes root rot in all crops. In legume crops, it not only attacks roots to reduce water and mineral uptake, but it destroys nitrogen-fixing nodules. Once established in the soil, it can remain viable for several years. This pathogen causes the most damage when chickpeas are grown in warm soil.

Control of root rot diseases can greatly enhance pulse crop production because these diseases reduce plant vigour and cause seedling blight in younger plants. Stands unaffected by seedling blight generally produce a dense, uniform canopy, while affected stands become thin, patchy and unevenly developed. Therefore it is especially important to treat seeds with a registered fungicide, since chickpeas planted into warm soils are susceptible to *Rhizoctonia* and those planted into cool soils are susceptible to *Pythium*. Moreover, no resistant cultivars have been found. The fungicides Vitaflo 280, Crown and Apron Maxx offered the most effective protection to chickpea seedlings, resulting in improved stand density, which translated into improved yield at harvest.

Table 1. Impact of inoculation with isolates from disease survey on survival and growth of seedlings of chickpea cv. Stanford[z] in a growth chamber trial.

Organism	Isolate	Survival	Root Rot (0-4)	Plant Height (cm)	Shoot Dry Weight (g)	Root Dry Weight (g)
--	ck	10.0 a	0.0 d	7.0 a	2.12 a	1.83 a
FO	Ckp05	9.0 a	0.6 c	6.6 ab	1.58 bc	1.61 abc
FO	Ckp09	6.8 b	3.7 a	2.4 c	0.23 e	0.46 d
FO	Ckp17	9.8 a	0.1 d	7.0 a	2.10 a	1.66 ab
FA	Ckp06	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e
FA	Ckp07	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e
FA	Ckp11	0.8 c	4.0 a	0.4 d	0.02 e	0.05 e
FS	Ckp03	9.0 a	1.1 b	5.7 b	1.18 d	1.30 c
FS	Ckp04	10.0 a	0.6 c	5.6 b	1.38 cd	1.56 abc
FS	Ckp08	9.3 a	0.9 bc	6.1 ab	1.48 bc	1.45 bc
FS	Ckp10	9.5 a	0.2 d	3.3 c	1.91 a	1.87 a
FS	Ckp15	9.8 a	0.7 bc	6.8 a	1.67 b	1.28 c
FS	Ckp16	9.0 a	0.8 bc	7.0 a	1.64 b	1.30 c
Rhiz	Ckp01	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e
Rhiz	Ckp02	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e
Rhiz	Ckp14	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e
Rhiz	R1	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e
Rhiz	R3	0.0 c	4.0 a	0.0 d	0.00 e	0.00 e

[z]Ten seeds per pot, 10 pots per treatment. Seedling survival and plant height were recorded 2 wk after seeding; shoot and root dry weights determined 1 month after seeding.

[y]FO- *Fusarium oxysporum*, FA- *F. avenaceum*, FS- *F. solani*, Rhiz- *Rhizoctonia solani*

Table 2. Pathogenicity of isolates of *Pythium* spp. on seedlings of chickpea cultivar Kabuli[z].

Isolate	Percent	Dry Weight (g)		Root Rot
		Shoot	Root	
KP-6	92 a	2.37 a	2.13 abc	1.52 d
Control	90 a	2.01 ab	2.47 a	0.64 e
KP-4	90 a	1.40 bcde	2.28 ab	1.48 d
KP-11	90 a	1.85 abc	1.98 abcd	1.74 bcd
KP-7	84 ab	2.17 a	1.94 abcd	1.70 cd
KP-1	82 ab	1.68 abcd	2.19 abc	2.44 ab
KP-8	82 ab	1.99 ab	2.11 abc	1.56 d
KP-9	80 abc	1.26 cde	1.81 bcd	2.38 abc
KP-5	64 cd	1.14 de	1.83 bcd	2.06 abcd
KP-3	58 cd	0.94 e	1.63 cd	2.08 abcd
KP-10	56 d	1.19 cde	1.49 d	2.48 a
KP-2	52 d	0.87 e	1.64 cd	2.54 a
Lsd	22.66	0.69	0.58	0.71

[z] Fifteen seeds per pot, eight pots per treatment. Seedling survival was recorded two weeks after seeding and seedling weights were recorded three weeks after seeding. Disease index rated on a scale of 0 (healthy) to 4 (severely diseased). Means in the same column followed by the same letter are not significantly different (P = 0.05) according to Duncan's New Multiple Range test.

Table 3. Effects of seed treatments on Pythium root rot of chickpea in greenhouse trials

		Kabuli					Desi				
	Rate (mL/kg)	Germ. (%)	Dead (%)	Dswt. (g)	Drwt. (g)	Root rot (0-4)	Germ. (%)	Dead (%)	Dswt. (g)	Drwt. (g)	Root rot (0-4)
C + A + p[z]	6 + 0.16	14.0 d	86.0 b	0.29 cd	0.44 b	3.47 b	62.0 d	38.0 b	1.90 c	2.17 a	2.49 b
C + A + p	3 + 0.16	26.0 bc	74.0 cd	0.44 bc	0.54 b	3.05 c	72.0 cd	28.0 bc	2.37 bc	2.31 a	1.96 c
A + p	0.32	34.0 b	66.0 d	0.67 b	0.61 b	3.14 bc	86.0 ab	14.0 de	2.74 b	2.35 a	1.71 c
A + p	0.16	19.0 cd	81.0 bc	0.48 bc	0.55 b	3.40 bc	77.0 bc	23.0 cd	2.12 c	2.11 a	1.93 c
V + p	3.3	0.0 e	100.0 a	0.00 d	0.00 c	4.00 a	9.0 e	91.0 a	0.25 d	2.73 b	3.72 a
V + A + p	3.3 + 1.6	20.0 cd	80.0 bc	0.45 bc	0.49 b	3.46 b	71.0 cd	29.0 bc	2.32 bc	2.21 a	1.89 c
Control		53.0 a	47.0 e	1.33 a	0.96 a	1.88 d	91.0 a	9.0 e	3.71 a	2.29 a	0.45 d
Pythium (p)		0.0 e	100.0 a	0.00 d	0.00 c	4.00 a	0.0 e	100.0 a	0.04 d	0.15 c	4.00 a

[z]C = Crown; A = Apron; V= Vitaflo 280; p = *Pythium*

Table 4. Effect of seed treatment fungicides on number of emerged seedlings and yield of Desi- and Kabuli-type chickpeas inoculated with *Pythium* at Brooks and Vegreville, Alberta in 1996 and 1997.

Treatment	Rate (mL/kg seed)	Brooks				Vegreville	
		Desi		Kabuli		Number of seedlings (Plants/6m)	
		Seedlings (Plants/6m)	Yield (T/ha)	Seedlings (Plants/6m)	Yield (T/ha)	Desi	Kabuli
Control		38.8 a*	1.28 a	19.4 a	0.41 c	27.3 b	0.22 c
Apron +P	0.16	31.8 b	1.10 ab	22.9 a	1.25 ab	31.8 a	32.3 b
Apron + Crown +P	0.16 + 3.0	30.6 b	1.02 ab	27.8 a	1.35 a	31.3 a	36.7 a
Apron +P	0.32	30.5 b	1.15 ab	27.7 a	1.08 ab	33.1 a	32.2 b
Apron + Crown +P	0.16 + 6.0	31.0 b	1.07 ab	23.3 a	0.90 b	33.8 a	37.0 a
Pythium (P)		29.2 b	0.89 b	16.0 a	0.37 c	25.6 b	0.26 c
Years:							
1996		41.0 a	0.10 b	28.2 a	0.32 b	36.6 a	26.7 a
1997		22.9 b	2.06 a	17.4 b	1.47 a	24.3 b	19.5 b

* Means within a column followed by the same letter are not significantly different using Duncan's Multiple Range Test ($P \leq 0.05$).

Table 5. Effect of seed treatment fungicides on seedling emergence and seed yield of Desi- and Kabuli- type chickpeas inoculated with P*ythium* at Brooks, AB in 1998.

Treatment	Rate (mL/kg seed)	Number of seedlings (Plants/6m)	Yield (T/ha)
Control		47.6 a*	2.46 a
Crown + Apron +P	3.0 + 0.16	38.0 bc	2.28 a
Apron +P	0.32	42.8 ab	2.20 ab
Apron +P	0.16	45.7 ab	2.31 a
Crown + Apron +P	6.0 +0.16	33.2 c	2.47 a
Vitaflo 280	3.3	8.9 d	1.18 c
Vitaflo 280 + Apron +P	3.3 + 0.16	49.1 a	2.26 a
Pythium (P)		14.3 d	1.32 bc
Cultivar:			
Desi		46.4 a	2.02 a
Kabuli		23.5 b	2.09 a

* Means within a column followed by the same letter are not significantly different using Duncan's Multiple Range Test ($P \leq 0.05$).

Table 6. Effect of seed treatments on number of emerged seedlings and seed yield of chickpea cv. B-90 at Brooks, Alberta in 1999.

Treatment	Rate (g ai/100 kg seed)	Emergence (Plants/6m)	Yield (T/ha)
Control	--	34.5 b*	0.19 abcd
Control+*Pythium* (*P*)	--	22.0 c	0.11 d
Apron XL+*P*	3.75	40.6 a	0.16 abcd
Apron XL+*P*	7.5	40.5 a	0.23 ab
Maxim+*P*	2.5	24.8 c	0.13 cd
Apron XL+ Maxim+*P*	7.5 + 2.5	43.5 a	0.15 bcd
Apron Maxx+*P*	3.75	43.2 a	0.26 a
Apron Maxx+*P*	7.5	41.9 a	0.21 abc
MAD[z]+*P*	2.5+7.5+12	41.6 a	0.23 ab
MAD+Adage+*P*	2.5+7.5+12+25	43.6 a	0.22 abc
MAD+Adage+*P*	2.5+7.5+12+50	43.4 a	0.15 bcd
MAD+ Helix Green+*P*	2.5+7.5+12+200	43.7 a	0.24 ab
Vitaflo 280 +*P*	88	32.7 b	0.13 cd

* Means within a column followed by the same letter are not significantly different for each experimental variable using Duncan's New Multiple Range Test ($P \leq 0.05$).

[z] Maxim+Apron XL+ Dividend

Table 7. Effect of seed treatments on number of emerged seedlings and seed yield of chickpea cv. B-90 at Brooks, Alberta in 2000.

Treatment	Rate (g ai/100 kg seed)	Emergence (Plants/6m)	Yield (T/ha)
Apron XL + Maxim +*P*[1]	3.75 + 2.5	62.6 a[2]	3.47 ab
Apron Maxx +*P*	3.75 + 2.5	63.0 a	3.67 a
MAD[3] +*P*	22	62.3 a	3.89 a
MAD + Cruiser +*P*	22 + 50	63.9 a	3.62 a
Vitaflo 280 +*P*	88	42.4 b	3.51 ab
Control +*P*	--	2.9 d	0.96 c
Control	--	34.0 c	2.51 b

1 Denotes inoculation with *Pythium*

2 Means within a column followed by the same letter are not significantly different for each experimental variable using Duncan's New Multiple Range Test (*P*0.05).

3 Maxim+Apron XL+Dividend

Table 8: Effect of seed treatment on survival and growth of chickpea inoculated with *Fusarium* at different concentrations.

Treatment	Rate mL/Kg	Low Concentration				High Concentration			
		Survival (%)	Dry Shoot Weight (g)	Dry Root Weight (g)	Root rot (0-4)	Survival (%)	Dry Shoot Weight (g)	Dry Root Weight (g)	Root rot (0-4)
C + A + F [z]	3 mL	50.0 bc	0.70 bc	0.56 bc	2.69 ab	19.0 c	0.22 d	0.27 c	3.56 a
C + A + F	6 mL	64.0 b	0.82 ab	0.61 b	2.29 bc	55.0 b	0.63 ab	2.57 b	2.60 b
V + A + F	3.3 mL	61.0 b	0.82 ab	0.95 a	2.10 c	54.0 b	0.57 ab	0.49 b	2.45 b
A + F	0.16 mL	38.0 c	0.57 c	0.44 cd	3.04 a	43.0 b	0.47 bc	0.57 b	2.87 b
Control (Uninoculated)		81.0 a	0.97 a	0.69 b	1.03 d	75.0 a	0.68 a	0.77 a	1.64 c
Fusarium (F)		35.0 c	0.51 c	0.39 d	2.95 a	23.0 c	0.32 cd	0.52 b	3.46 a

[z] C = Crown; A= Apron; V= Vitaflo 280; F= *Fusarium*

Table 9. Effect of seed treatment on number of seedlings and seed yield of chickpea inoculated with *Fusarium* at Brooks and Vegreville, Alberta, 1997 and 1998.

Treatment	Rate (mL/kg)	Percent Emergence			Yield (T/ha)	
		Brooks, 1997	Vegreville, 1997	Brooks, 1998	1997	1998
Crown + Apron + F[z]	6 + 0.32	67.5 a	43.7 b	52.1 ab	1.63 a	1.01 a
Crown + Apron + F	3 + 0.32	68.8 a	50.5 a	56.5 ab	1.69 a	1.10 a
Apron + F	0.32	45.8 b	45.0 ab	70 8 a	1.45 ab	1.01 a
Vitaflo + Apron + F	3.3 + 0.32			54.3 ab		0.92 ab
Control (Uninoculated)		45.3 b	44.9 ab	40.0 bc	1.30 b	1.01 a
Fusarium (F)		47.8 b	28.5 c	30.1 c	1.34 b	0.80 b

* Means within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P 0.05).

[z] Denotes inoculation with *Fusarium avenaceum*

Table 10. Effect of seed treatments on number of emerged seedlings and seed yield of chickpea cv. B-90 at Brooks, Alberta in 1999.

Treatment	Rate (g ai/100 kg seed)	Emergence (Plants/6m)	Yield (T/ha)
Control	--	34.2 bc*	0.12 e
Control+*Fusarium* (*F*)	--	17.0 e	0.10 e
Apron XL+*F*	3.75	23.2 d	0.12 e
Apron XL+*F*	7.5	20.7 de	0.12 e
Maxim+*F*	2.5	30.2 c	0.23 d
Apron XL+ Maxim+*F*	7.5 + 2.5	42.8 a	0.29 cd
Apron Maxx+*F*	3.75	41.7 a	0.28 cd
Apron Maxx+*F*	7.5	42.7 a	0.34 bc
MAD[z]+*F*	7.5+2.5+12	41.4 a	0.22 d
MAD+Adage+*F*	7.5+2.5+12+25	43.1 a	0.39 ab
MAD+Adage+*F*	7.5+2.5+12+50	41.3 a	0.46 a
MAD+Helix Green+*F*	7.5+2.5+12+200	44.1 a	0.42 ab
Vitaflo 280 +*F*	88	34.5 b	0.22 d

* Means within a column followed by the same letter are not significantly different for each experimental variable using Duncan's New Multiple Range Test ($P \leq 0.05$).

[z] Maxim+ Apron XL+ Dividend

Table 11. Effect of seed treatments on number of emerged seedlings and seed yield of chickpea cv. B-90 at Brooks, Alberta in 2000.

Treatment	Rate (g ai/100 kg seed)	No. seedlings /6m	Yield (T/ha)
Apron XL + Maxim +*F*[1]	7.5 + 2.5	43.6 a[2]	3.57 a
Apron Maxx +*F*	3.75	46.6 a	3.61 a
MAD[3] +*F*	7.5+2.5+12	47.4 a	3.57 a
MAD + Cruiser +*F*	7.5+2.5+25	48.0 a	3.06 a
Vitaflo 280 +*F*	88	36.0 b	3.18 a
Control +*F*	--	7.1 c	1.52 b
Control	--	33.3 b	3.33 a

1 Denotes inoculation with *Fusarium.*

2 Means within a column followed by the same letter are not significantly different for each experimental variable using Duncan's New Multiple Range Test (*P*0.05).

3 Maxim+Apron XL+Dividend

Figure 1. Effect of inoculum density on survival, shoot and root productivity and root rot of chickpea cvs. Sanford and Tyson

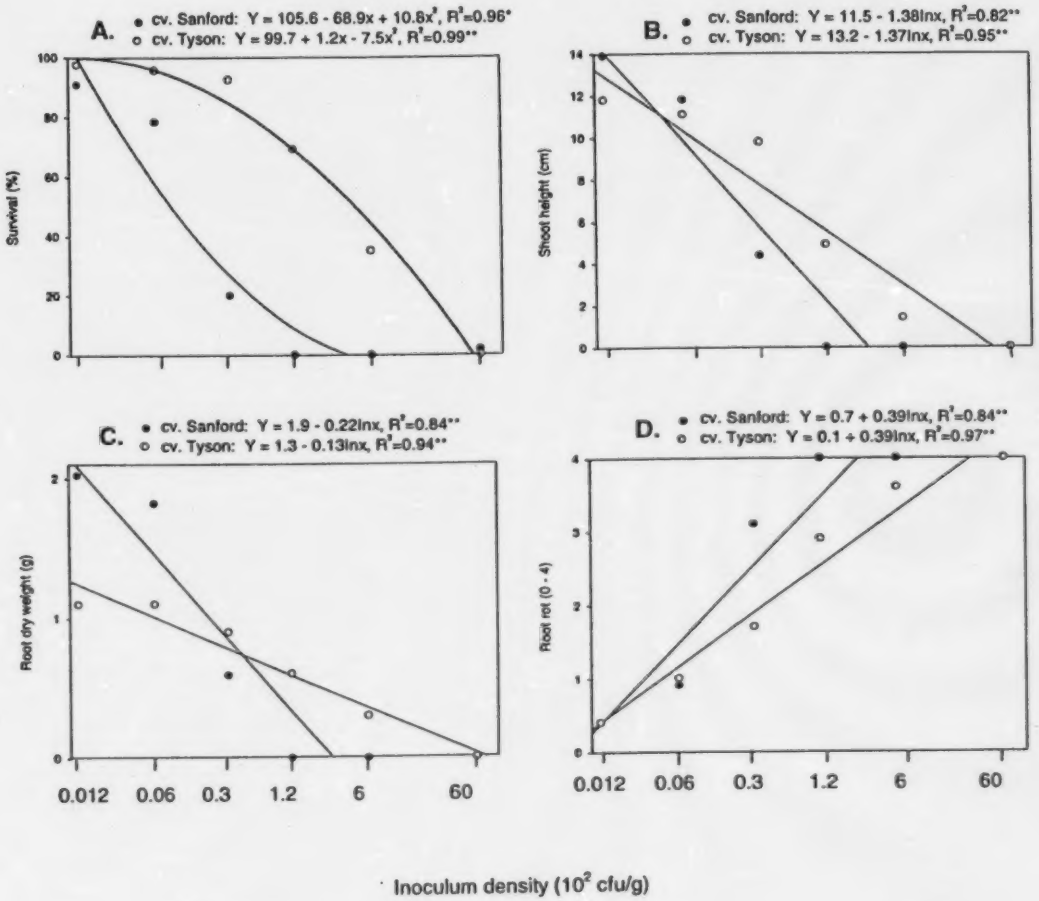
A.
• cv. Sanford: Y = 105.6 - 68.9x + 10.8x², R²=0.96*
o cv. Tyson: Y = 99.7 + 1.2x - 7.5x², R²=0.99**
Survival (%)
B.
• cv. Sanford: Y = 11.5 - 1.38lnx, R²=0.82**
o cv. Tyson: Y = 13.2 - 1.37lnx, R²=0.95**
Shoot height (cm)
C.
• cv. Sanford: Y = 1.9 - 0.22lnx, R²=0.84**
o cv. Tyson: Y = 1.3 - 0.13lnx, R²=0.94**
Root dry weight (g)
D.
• cv. Sanford: Y = 0.7 + 0.39lnx, R²=0.84**
o cv. Tyson: Y = 0.1 + 0.39lnx, R²=0.97**
Root rot (0 - 4)
0.012 0.06 0.3 1.2 6 60
Inoculum density (10² cfu/g)

Table 12. **Effect of day/night temperature regime on the impact of *Rhizoctonia solani* on field chickpea seedlings[¶].**

Temperature (°C)		Root rot (0-3)		Shoot infection(0-1)			Shoot height (mm)		
Mean	Day/ night	Sanford	Tyson	Sanford	Tyson	Control Sanford	Control Tyson	Sanford	Tyson
7.5	10/5	0.5 c[†]	0.3 g	0.0 c	0.0 e	0.0 b	22.9 a	0.0 b	17.4 bcde
10.0	15/5	0.3 c	0.7 fg	0.0 c	0.1 cde	8.3 ab	23.6 a	1.9 b	24.0 abc
12.5	15/10	2.2 b	1.0 ef	0.5 b	0.1 de	5.6 ab	21.6 a	3.9 ab	24.4 ab
	20/5	2.7 a	1.6 de	0.5 b	0.5 bc	4.8 ab	27.0 a	3.7 ab	28.7 ab
15.0	20/10	2.9 a	1.4 de	0.9 a	0.4 cd	5.4 ab	28.0 a	3.9 ab	26.7 ab
17.5	20/15	3.0 a	2.0 cd	1.0 a	0.9 a	8.0 ab	30.3 a	1.3 b	21.0 bcd
	25/10	3.0 a	2.1 bc	1.0 a	0.7 ab	17.1 ab	28.5 a	9.3 a	33.9 a
20.0	25/15	3.0 a	2.5 abc	1.0 a	0.9 a	20.9 a	29.8 a	5.8 ab	28.9 ab
22.5	25/20	3.0 a	2.7 ab	1.0 a	1.0 a	13.5 ab	32.4 a	4.4 ab	19.8 bcde
	30/15	3.0 a	2.5 abc	1.0 a	1.0 a	12.1 ab	28.4 a	3.5 ab	11.5 cde
25.0	30/20	3.0 a	2.9 a	1.0 a	1.0 a	8.3 ab	10.4 a	5.0 ab	9.2 de
27.5	30/25	3.0 a	3.0 a	1.0 a	1.0 a	14.3 ab	17.1 a	3.3 ab	7.5 e
Mean		**2.5**	**1.9**	**0.74**	**0.63**	**9.9**	**25.0**	**3.8**	**21.1**

¶ The mean value in the control for root rot severity was 0.93, and 0.13 for shoot infection.

† Means for a response variable followed by the same letter did not differ based on Duncan's Multiple Range Test at $P \leq 0.05$.

Table 13. Effect of temperature and inoculation with *Rhizoctonia solani* on emergence, root rot and vegetative productivity of chickpea in a greenhouse study.

	Sanford				Tyson			
Temperature (° C)	Seedlings/ Pot	Shoot height (cm)	Root dry wt. (g)	Root rot (0-4)	Seedlings/ Pot	Shoot height (cm)	Root dry wt. (g)	Root rot (0-4)
Noninoculated:								
12/1	9.9 a	1.5 c	3.8 a	0.0 b	9.5 a	2.7 c	1.1 b	0.1 a
17/3	9.9 a	5.5 b	2.9 b	0.1 b	9.0 a	7.2 b	1.2 b	0.1 a
21/8	9.9 a	15.0 a	2.7 c	0.2 a	9.5 a	13.8 a	1.7 a	0.2 a
Low inoculum concentration (1:500):								
12/1	0.6 c	0.1 c	0.6 c	3.8 a	8.3 a	2.3 c	1.0 a	1.0 c
17/3	8.8 b	5.5 b	2.7 a	1.1 c	9.0 a	5.7 b	1.0 a	1.5 b
21/8	9.7 a	10.3 a	1.7 b	2.2 b	8.0 a	8.7 a	1.0 a	2.7 a
High inoculum concentration (1:250):								
12/1	1.0 b	0.1 b	0.7 b	3.7 b	8.5 a	2.2 c	1.0 a	1.3 c
17/3	9.6 a	4.6 a	2.7 a	1.7 c	8.7 a	5.0 b	1.0 a	1.8 b
21/8	0.2 c	0.2 b	0.0 c	4.0 a	6.3 b	7.2 a	1.0 a	2.8 a

Table. 14 Effect of rhizoctonia root severity on level of nodulation and fresh weight of nodules of chickpea cultivars Sanford and Tyson in soils infested with *R. solani*.

Cultivar	Root Rot	Nodulation	Nodule fresh weight (mg/plant)	Root dry weight
Sanford	0	2.4 a*	109 a	0.45 a
	1	1.8 b	101 a	0.36 b
	2	1.5 b	66 a	0.33 bc
	3	1.0 c	62 a	0.28 c
	4	0.3 d	7 b	0.10 d
Tyson	0	2.2 a	34 a	0.21 a
	1	1.6 b	28 ab	0.20 a
	2	1.5 b	25 ab	0.19 a
	3	0.9 c	19 b	0.15 b
	4	0.2 d	3 c	0.06 c

* Means within a column followed by the same letter do not differ significantly according to Duncan's Multiple Range Test.

Table 15. Effect of seeding depth on seedling emergence, survival, shoot and root dry weights, and root rot of two cultivars of chickpea in soils infested with *Rhizoctonia solani*.

Seeding depth (Treatment)[x]	Sanford[y]				Tyson			
	Seedling survival (%)	Root rot severity	Shoot Dry Wt. (g)	Root Dry Wt. (g)	Seedling survival (%)	Root rot severity	Shoot Dry Wt. (g)	Root Dry Wt. (g)
2 cm (-)	94 a[z]	0.1 c	3.1 a	2.3 a	9.4 a	0.2 c	1.8 a	1.4 a
2 cm (+)	78 b	2.6 b	1.7 b	1.6 b	7.3 b	3.0 b	1.0 b	0.7 b
5 cm (-)	89 a	0.0 c	2.8 a	2.4 a	9.3 a	0.0 c	1.7 a	1.3 a
5 cm (+)	50 c	3.1 a	1.0 c	1.8 b	4.8 c	3.4 a	0.5 c	0.7 b

[x](+) inoculated with R. solani @ 1/250 v/v; (-) not inoculated.
[y]Ten seeds per pot, 12 pots per treatment. Seedling emergence recorded 1 week after seeding; seedling height, shoot and root dry weights, and root rot severity assessed 4 weeks after seeding. Root rot severity rated on a scale of 0 (healthy) to 4 (severely diseased).
[z]Means within a column followed by the same letters are not significantly different using Duncan's New Multiple Range test (P=0.05).

Table 16. Effect of *Rhizoctonia solani* on root rot severity in various crop species (1/300).

Host	Inoc.	Survival	Plant height (cm)	Shoot wt. (g)	Rot rot severity
Alfalfa					
cv. Algonquin	-	8.50±1.38	1.75±0.26	0.04±0.01	0
	+	3.83±2.71**	0.83±0.56**	0.02±0.01**	2.13±1.37**
cv. Peace	-	6.67±3.20	1.63±0.80	0.04±0.02	0.02±0.04
	+	3.83±2.14	0.85±0.32	0.03±0.02	2.07±1.43**
Barley					
cv. Lacombe	-	10.0	18.2±0.95	0.45±0.04	0.05±0.12
	+	9.83±0.41	16.7±1.26*	0.44±0.06	0.57±0.08**
cv. Pheonix	-	8.83±1.17	14.6±2.77	0.31±0.08	0.03±0.08
	+	8.00±1.26	13.4±2.93	0.35±0.08	0.92±0.22**
Canola					
cv. Tobin	-	8.50±1.22	2.63±0.43	0.15±0.04	0
	+	2.33±1.51**	0.58±0.46**	0.03±0.04**	1.45±1.24*
cv. Westar	-	10.0	3.95±0.69	0.23±0.06	0
	+	3.67±2.58**	1.58±1.17**	0.10±0.08**	2.25±1.40**
Chickpea					
cv. Sanford	-	9.83±0.41	7.18±0.76	0.96±0.14	0.05±0.08
	+	7.17±1.72**	4.08±1.77**	0.55±0.27**	2.22±0.68**
cv. Tyson	-	9.00±0.89	4.98±1.28	0.42±0.19	0
	+	4.67±3.88*	1.82±1.82**	0.15±0.15*	3.42±0.63**
Clover					
cv. Alsike	-	9.00±0.63	0.93±0.14	0.02±0.01	0
	+	4.50±2.07**	0.45±0.27**	0.01±0.01*	2.00±1.24**
cv. Red	-	9.17±0.98	1.50±0.19	0.04±0.01	0
	+	3.83±1.60**	0.48±0.27**	0.01±0.01**	1.47±1.05**
Dry Bean					
cv. Earlinray	-	10.0	12.1±1.25	2.63±0.17	0
	+	10.0	10.4±0.97*	2.26±0.23*	0.88±0.17**
cv. Great North	-	9.50±0.55	13.8±1.67	2.37±0.30	0
	+	9.83±0.41	12.4±1.78	2.24±0.16	1.53±0.22**

cv. U1906	-	9.83±0.41	8.25±0.85	1.16±0.30	0
	+	8.50±1.38*	6.20±1.57*	0.79±0.18*	1.37±0.55**
cv. Viva	-	9.67±0.52	8.07±0.94	1.48±0.10	0.02±0.04
	+	9.17±0.98	5.38±0.89**	1.27±0.20*	1.15±0.39**
Flax					
cv. Nolan	-	9.00±0.63	3.55±0.25	0.10±0.02	0
	+	1.67±1.03**	0.63±0.42**	0.02±0.02**	1.13±1.59
cv. Somme	-	10.0	3.75±0.32	0.12±0.02	0.02±0.04
	+	0.67±1.03**	0.27±0.41**	0.01±0.02**	3.25±0.91**
Lentil					
cv. Eston	-	9.67±0.52	4.93±1.30	0.19±0.09	0.03±0.08
	+	2.67±2.42**	1.30±1.46**	0.04±0.06**	3.23±0.86**
cv. Laird	-	9.17±0.98	8.02±0.86	0.45±0.06	0.02±0.04
	+	2.83±2.79**	1.37±1.73**	0.06±0.08**	2.93±0.90**
Oat					
cv. Calibre	-	9.33±0.82	16.2±3.41	0.30±0.07	0.02±0.04
	+	8.67±0.52	10.6±2.36**	0.20±0.06*	1.60±0.67**
cv. Derby	-	10.0	17.9±2.59	0.28±0.08	0
	+	9.33±0.52*	15.9±2.52	0.29±0.05	0.53±0.26**
Pea					
cv. Highlight	-	9.33±0.82	5.30±1.31	0.54±0.15	0.07±0.10
	+	5.50±2.35**	1.73±0.88**	0.17±0.10**	3.25±0.31**
cv. Montana	-	7.00±1.41	2.42±0.52	0.41±0.12	0.22±0.37
	+	3.83±1.72**	1.08±0.77**	0.16±0.15**	3.02±0.56**
Soybean					
cv. Maple	-	7.83±1.72	2.72±0.87	0.90±0.17	0.02±0.04
Amber	+	6.50±0.84	2.18±0.56	0.79±0.17	1.58±0.43**
Wheat					
cv. Fremont	-	9.00±0.63	14.7±2.36	0.25±0.05	0.05±0.05
	+	8.17±1.17	12.5±2.58	0.23±0.05	1.12±0.42**
cv. Michael	-	9.50±0.55	18.9±1.42	0.30±0.05	0.07±0.16
	+	8.00±0.89**	15.1±2.25**	0.24±0.05	0.82±0.18**

Table 17 . Effect of chemical fungicidal seed treatments on seedling survival and seed yield of chickpea cvs. Sanford and Tyson at Brooks, Alberta in 1999.

Seed Treatment	Rate (mL/kg seed)	Emergence (Plants/6m)	Seed yield (T/ha)
VITAFLO+APRON +*R*[1]	3.3 + 5	32.4 a	1.97 a
U2727+APRON+*R*	4.0 + 5	11.8 c	1.54 a
LO 176+APRON+*R*	1.25 + 5	6.5 d	0.55 bc
LO 176+APRON+*R*	2.5 + 5	4.5 d	0.54 bc
Control+*R*	--	3.2 d	0.27 c
Control	--	23.4 b	0.98 b
Cultivar			
Sanford		13.0 a	1.53 a
Tyson		14.3 a	0.43 b

* Means within a column followed by the same letter are not significantly different using Duncan's New Multiple Range Test ($P \leq 0.05$).

[1] Denotes inoculation with *Rhizoctonia solani*.

Table 18. Effects of fungicidal seed treatments on plant stand and seed yield of chickpea cvs. Myles and Sanford at Brooks, Alberta in 2000.

Treatment	Rate (mL/kg seed)	Emergence (Plants/6m)	Seed yield (T/ha)
Vitaflo + Apron +*R*[1]	3.3 + 0.16	7.5 b[2]	0.64 b
Crown +*R*	3.0	1.5 c	0.17 c
Crown +*R*	6.0	5.6 b	0.64 b
LS 176+Apron +*R*	3.1 + 0.16	1.6 c	0.27 c
Apron +*R*	0.16	0.5 c	0.03 c
Control +*R*	--	0.1 c	0.02 c
Control	--	23.2 a	1.20 a
Cultivar			
Sanford		3.0 b	0.29 b
Myles		8.4 a	0.56 a

1 Denotes inoculation with *Rhizoctonia solani*.

2 Means within a column within a category followed by the same letter are not significantly different using Duncan's New Multiple Range Test ($P \leq 0.05$).

Table 19. Effects of fungicidal seed treatments on plant stand and seed yield of chickpea cvs. Myles and Sanford at Saskatoon, Saskatchewan in 2000.

Treatment	Rate (mL/kg)	Emergence (Plants/6m)	Rot	Yield (T/ha)
Vitaflo 280 + Apron FL + R	2.6 + 0.16	40.2 ab	2.0 a	3.18 b
Vitaflo 280 + R	2.6	39.6 ab	2.0 a	2.34 bc
Vitaflo 280 + R	3.3	43.2 a	2.0 a	2.37 bc
Captan	2.1	38.4 ab	2.1 a	1.78 cd
LS 176 + Metalaxyl + R	3.1 + 0.16	25.8 bc	1.8 a	1.42 de
Inoculated Control + R	-	19.2 c	2.1 a	0.66 e
Uninoculated Control + R	-	54.6 a	1.7 a	4.02 a
LSD		15.1	0.39	0.83

Cultivar	Emergence	Rot	Yield
Sanford	36.0 a	2.0 a	1.96 b
Myles	37.8 a	2.0 a	2.49 a
LSD	8.0	0.21	0.45

Table 20. Effect of seed treatments on number of emerged seedlings and seed yield of chickpea cv. B-90 at Brooks, Alberta in 2000.

Treatment	Rate (g ai/100 kg seed)	Emergence (Plants/6m)	Yield (T/ha)
Apron XL+ Maxim +*R*[1]	7.5 + 2.5	2.0 c[2]	0.57 c
Apron Maxx +*R*	3.75	1.4 c	0.55 c
MAD[3] +*R*	7.5+2.5+12	7.3 b	1.71 b
MAD + Cruiser +*R*	7.5+2.5+12+25	8.5 b	1.63 b
Vitaflo 280 +*R*	88	8.4 b	1.29 b
Control +*R*	--	0.1 c	0.01 c
Control	--	36.6 a	3.39 a

1 Denotes inoculation with *Rhizoctonia*

2 Means within a column followed by the same letter are not significantly different for each experimental variable using Duncan's New Multiple Range Test (*P*.0.05).

3 MAXIM+APRON XL+DIVIDEND

Table 21. Effects of fungicidal seed treatments on plant stand and seed yield of chickpea cv. Dwelley at Brooks, Alberta in 2001.

Treatment	Rate (mL/kg seed)	Stand (plants/6m)	Seed yield (T/ha)
Control +*R*[1]		0.0 e[2]	0.00 c
L0020[3] + U2521[4] +*R*	0.16 + 3.0	49.4 ab	1.65 a
L1022[5] +*R*	3.1	35.6 c	2.09 a
L0020 + L1030[6] +*R*	0.16 + 1.0	52.2 ab	2.38 a
L0020 + U2521 +*R*	0.16 + 4.5	54.9 a	2.25 a
L0020 + U2051[7] +*R*	0.16 + 3.3	55.9 a	1.98 a
L0020 + L1031[8] +*R*	0.16 + 1.33	51.4 ab	1.83 a
L0020 (Apron) + *R*	0.16	11.8 d	0.87 b
L0202[9] + *R*	4.4	55.7 a	1.94 a
Control	--	1.8 e	0.34 bc

1 Denotes inoculation with *Rhizoctonia solani*.
2 Means within a column followed by the same letter are not significantly different using Duncan's New Multiple Range Test ($P \leq 0.05$).
3 Metalaxyl (Apron)
4 Crown
5 metalaxyl + ipconazole
6 HEC 5725
7 Vitaflo 280 (carbathiin+thiram)
8 HEC 5725 + triazolinthion
9 Carbathiin + thiram + metalaxyl

Table 22. Effect of seed treatments on number of emerged seedlings and seed yield of chickpea cv. B-90 at Brooks, Alberta in 2001.

Treatment	Rate (g ai/100 kg seed)	Stand (plants/6m)	Yield (T/ha)
Apron Maxx +*R*	6.25	28.8 a[2]	1.77 a
Apron Maxx +*R*	12.5	34.4 a	2.49 a
Crown +*R*	90.0	35.9 a	2.15 a
Control +*R*	-	0.9 b	0.04 b
Control	-	27.4 a	1.71 a

[1] Denotes inoculation with *Rhizoctonia*

[2] Means within a column followed by the same letter are not significantly different for each experimental variable using Duncan's New Multiple Range Test ($P \leq 0.05$).

Table 23. The effect of seed treatment and mechanical damage on seedling emergence and seed yield of chickpea in field trials at Brooks in Alberta, 1999–2000.

Treatment	Damage	Emergence (Plants/6m)		Yield (T/ha)	
		1999	2000	1999	2000
Cultivar:					
B-90	-	42.9 a[z]	17.5 b	1.61 a	1.82 a
B-90	+	42.4 a	17.7 b	1.21 b	1.59 ab
Sanford	-	35.1 b	20.3 b	1.67 a	1.35 b
Sanford	+	33.2 b	18.1 b	1.13 b	1.24 b
Tyson	-	41.0 a	-	0.75 c	-
Tyson	+	39.9 a	-	0.69 c	-
Myles	-	-	27.9 a	-	1.89 a
Myles	+	-	28.9 a	-	1.94 a
Inoculation:					
Inoculated		25.3 b	6.7 b	0.74 b	0.93 b
Noninoculated		52.8 a	36.7 a	1.62 a	2.35 a
Fungicide Treatment:					
Vitaflo + Apron		57.8 a	30.4 a	1.48 a	2.33 a
Control		20.4 b	13.1 b	0.88 b	0.94 b

[z]Means in a column within each group followed by a common letter are not significantly different at $P \leq 0.05$.

Table 24. Chickpea cultivar vs. Rhizoctonia concentrations in a greenhouse study

Concentration	Cultivar	Number of Seedlings	Root Rot (0-4)	Shoot Height (cm)	Shoot Dry Weight (g)	Root Dry Weight (g)
Control	B90	10.0 a	0.00 b	16.3 ab	1.38 b	0.92 c
Control	Dwelley	10.0 a	0.08 b	12.0 e	1.43 b	1.92 ab
Control	Myles	9.3 b	0.36 a	12.7 d	0.71 c	0.89 c
Control	Sanford	10.0 a	0.02 b	16.2 ab	1.40 b	1.98 a
Control	Tyson	9.6 b	0.05 b	16.8 a	0.83 c	0.94 c
Control	Xena	10.0 a	0.00 b	15.3 c	1.99 a	1.99 a
Control	Yuma	10.0 a	0.02 b	16.0 b	1.97 a	1.81 b
Low (1:500)	B90	8.92 ab	2.32 bc	12.0 c	0.90 c	0.69 c
Low	Dwelley	9.17 ab	2.59 ab	8.2 e	0.82 c	1.89 a
Low	Myles	7.92 bc	2.46 ab	9.8 d	0.57 d	0.57 cd
Low	Sanford	9.58 a	1.98 cd	12.7 bc	1.26 b	1.98 a
Low	Tyson	7.25 c	2.88 a	13.8 ab	0.60 d	0.44 d
Low	Xena	9.50 a	1.69 d	12.4 bc	1.24 b	1.99 a
Low	Yuma	9.42 a	1.93 cd	14.4 a	1.56 a	1.49 b
High (1:250)	B90	8.75 ab	2.44 bc	12.9 a	0.90 b	0.88 c
High	Dwelley	8.83 ab	2.67 b	8.9 b	0.83 b	1.79 b
High	Myles	7.25 c	3.20 a	9.8 b	0.43 d	0.59 d
High	Sanford	9.33 a	2.08 c	12.5 a	1.23 a	1.61 b
High	Tyson	7.91 bc	3.12 a	13.7 a	0.63 c	0.49 d
High	Xena	9.50 a	1.69 d	13.3 a	1.30 a	2.13 a
High	Yuma	9.17 a	2.38 bc	13.2 a	1.31 a	1.76 b

Table 25. Comparison of the reaction of seven chickpea cultivars to rhizoctonia root rot at Brooks, Alberta.

Cultivar	1999 (Inoculated only)		2000 (Inoculated only)		2001 Noninoculated		2001 Inoculated	
	Emergence (Plants/6m)	Yield (T/ha)	Emergence (Plants/6m)	Yield (T/ha)	Emergence (Plants/6m)	Yield (T/ha)	Emergence (Plants/6m)	Yield (T/ha)
Myles	4.6 ab	0.38 a	3.5 a	0.26 a	46.3 a	1.07 ab	4.1 b	0.60 ab
Tyson	2.5 bc	0.02 b						
Yuma	6.3 a	0.18 ab	2.9 ab	0.26 a	47.3 a	0.74 ab	11.8 a	0.65 ab
B-90	4.4 ab	0.27 ab	2.5 ab	0.29 a	39.6 a	2.12 a	2.6 b	0.35 b
Xena	4.6 ab	0.15 ab			37.4 a	0.43 b	7.6 ab	1.16 a
Sanford	1.8 bc	0.31 ab	1.1 ab	0.09 a	42.9 a	1.65 ab	6.4 b	0.60 ab
Dwelley	0.4 c	0.04 b	0.8 b	0.04 a	34.2 a	1.25 ab	6.1 b	0.73 ab
Evans					44.4 a	1.68 ab	6.5 b	0.68 ab
LSD			2.3	0.24	13.1	1.28	4.5	0.55

Table 26. Effect of seeding date on seedling survival and seed yield of chickpea in field trials inoculated with *Rhizoctonia solani* at two locations in western Canada in 2000 and 2001.

Cultivar	Brooks, 2000		Saskatoon, 2000			Brooks, 2001	
	Emergence (Plants/6m)	Yield (T/ha)	Emergence (Plants/6m)	Yield (T/ha)	Rot (0-3)	Emergence (Plants/6m)	Yield (T/ha)
Dwelley							
Seeding Date 1	22.0 a	1.10 a	29.4 a	0.74 b	0.88 a	15.8 b	2.47 b
Seeding Date 2	24.4 a	1.09 a	28.8 a	1.00 a	0.64 a	30.8 a	3.52 a
Seeding Date 3	6.0 b	0.28 b	36.0 a	0.56 b	0.60 a	30.0 a	2.75 ab
LSD	4.5	0.42	10.8	0.26	0.51	4.9	0.85
Inoculation							
Inoculated	3.0 b	0.16 b	13.8 b	0.54 b	0.72 a	8.9 b	1.51 b
Noninoculated	32.0 a	1.49 a	49.2 a	1.00 a	0.73 a	42.2 a	4.32 a
LSD	3.7	0.34	9.0	0.21	0.39	4.0	0.69
Myles							
Seeding Date 1	16.7 a	1.45 a	33.0 a	2.23 a	0.36 b	27.6 a	2.84 a
Seeding Date 2	21.3 a	1.64 a	27.0 a	1.58 a	1.03 a	30.2 a	2.23 a
Seeding Date 3	1.6 b	0.20 b	27.6 a	1.99 a	0.63 ab	30.2 a	2.85 a
LSD	4.6	0.68	7.8	1.33	0.55	4.3	1.06
Inoculation							
Inoculated	0.7 b	0.10 b	12.0 b	0.98 b	0.55 a	10.3 b	2.28 a
Noninoculated	25.7 a	2.10 a	46.8 a	2.89 a	0.76 a	48.4 a	3.00 a
LSD	3.8	0.55	6.6	1.09	0.45	3.5	0.86

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Technology Transfer

List of Presentations Arising from Project

Papers

1. Hwang, S.F., K.F. Chang, B.D. Gossen, G.D. Turnbull and R.J. Howard. 2002. Etiology and severity of rhizoctonia seedling blight and root rot of chickpea on the Canadian Prairies. Can. J. Plant Science (in preparation).

Poster and Oral Presentations

1. Hwang, S.F., K.F. Chang, B.D. Gossen, G.D. Turnbull and R.J. Howard. 2002. Impact and management of rhizoctonia seedling blight and root rot in chickpea. Agronomy Conference 2001 Proceedings, Jan. 16-17, 2002. Edmonton, AB. pp. 81-83.
2. Hwang, S.F., K.F. Chang, B.D. Gossen, G.D. Turnbull and R.J. Howard. 2002. Etiology and chemical control of rhizoctonia seedling blight and root rot in chickpea. Saskatchewan Pulse Growers Pulse Days 2002 Proceedings, Jan. 7-8, 2002. Saskatoon, SK. p. 88..
3. Hwang, S.F., K.F. Chang, B.D. Gossen, and G.D. Turnbull. 2000. Effects of chemical seed treatments, soil temperature and seed damage on rhizoctonia seedling blight and seed yield of chickpea. Third Pulse Crop Research Proceedings, Nov. 19-21, 2000, Winnipeg, Manitoba. p. 24.
4. S.F. Hwang, K.F. Chang, B.D. Gossen, G.D. Turnbull and R.J. Howard. 2000. Etiology and chemical control of rhizoctonia seedling blight and root rot in chickpea. Third International Symposium on Rhizoctonia IRS 2000 Proceedings, National Chung Hsing University, Taichung, Taiwan (ROC), 17-20 August 2000. p. 103.

5. Hwang S. F., K.F. Chang, R. J. Howard, and G.D. Turnbull. 1998. Chemical control of soil-borne seedling diseases in field pea and chickpea. Progress Reports on Pulse Crop Research in Western Canada, Vol 3: pp. 76-77, Nov. 27-28, 1998, The 2nd Pulse Crop Research Workshop, Saskatoon, Saskatchewan.

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1. Gossen, B.D., S.F. Hwang, and P. Pearse. 2001. Seedling blight of pulses. Agriculture and Agri-Food Canada Research Branch, Research Letter 01-01, May 4, 2001. http://res2.agr.ca/saskatoon/resres.html#rl

2. Hwang, S.F. and B.D. Gossen. 2000. Watch out for root rot in chickpea! The Saskatchewan Pulse Grower, Winter 2000, 16 (4): p. 16.

Abstracts

1. Gossen, B.D., S.F. Hwang and A.G. Thomas. 2000. An improved technique to assess the impact of temperature on seedling infection. Can. J. Plant Pathology 22: 185.

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1. Chang, K.F., Howard, R.J., Hwang, S.F., Turnbull, G.D., and Wang, H. 2001. Evaluation of Fungicidal Seed Treatments to Control Rhizoctonia Seedling Blight and Root Rot of Chickpea in 2001. Pest Management Research Report – Insects and Diseases. Agriculture Canada, Ottawa. In Press.

2. Chang, K.F., Howard, R.J., Hwang, S.F., and Turnbull, G.D. 2001. Evaluation of Fungicidal Seed Treatments for the Control of Rhizoctonia Seedling Blight and

Root Rot of Chickpea in Alberta in 2001. Pest Management Research Report – Insects and Diseases. Agriculture Canada, Ottawa. In Press.

3. Chang, K.F., Howard, R.J., Hwang, S.F., Turnbull, G.D. and Wang, H. 2000. Evaluation of Fungicidal Seed Treatments to Control Rhizoctonia Root Rot of Chickpea in 2000. Pest Management Research Report – Insects and Diseases. Agriculture Canada, Ottawa. p. 252-253 (PMR Report #98)
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1. Wang, H., G.D. Turnbull, S.F. Hwang, K.F. Chang, and R.J. Howard. 1999. Disease survey of chickpea in west-central Saskatchewan in 1998. Can. Plant Dis. Surv. 79: 105-107.

Etiology and Severity of Rhizoctonia Seedling Blight and Root Rot of Chickpea on the Canadian Prairies

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Introduction

Chickpea (*Cicer arietinum* L.) has become a popular crop for the low moisture areas of Saskatchewan and Alberta. Seeded area has increased from zero to more than one million acres over the past five years on the Canadian prairies. However, field surveys in 2000 and 2001 revealed many thin, patchy stands. Plants were stunted and some exhibited a wilt-like collapse (Fig. 1). Closer examination of taproots showed girdling by brownish-black lesions near the soil surface. *Rhizoctonia solani* Kühn (Fig. 2) was commonly isolated from affected plants. In many cases, the level of root disease was sufficient to limit crop productivity.

Control of root rot diseases can greatly enhance pulse crop production because root rot limits plant vigour and the same pathogens cause seedling blight in younger plants. Plants with healthy root systems efficiently utilize fertilizer and water to achieve their yield potential. Stands unaffected by seedling blight produce a dense, uniform canopy, while affected stands become thin, patchy and unevenly developed. Rapid pathogen growth, high pathogen density and slow seedling development, caused by unfavourable temperatures or low-quality seed, all increase the likelihood of infection by soil pathogens.

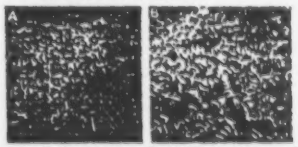

Figure 1. Chickpea plants affected by root rot symptoms (A) Healthy chickpea plants (B)

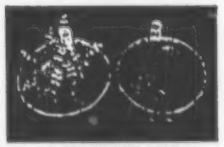

Figure 2. *Rhizoctonia* killed 100% of chickpea seedlings (R)

Objectives

1. to assess the pathogenicity of isolates of *R. solani* on chickpea seedlings
2. to determine the impact of rhizoctonia seedling blight and root rot on establishment, nodulation and seed yield of chickpea
3. to determine the effect of seeding depth on seed and seedling infection
4. to determine the efficacy of fungicide seed treatments to improve seedling establishment and seed yield of chickpea under field conditions.

Methods

Pathogenicity Chickpea seeds were planted into soil inoculated with isolates collected from disease surveys. Seedling survival, root rot severity, shoot height and shoot and root dry weight were recorded after 3 wk.

Impact of seeding depth on severity of root rot and seedling blight Chickpea seed planted in infested or noninfested soil mixture at either 2- or 5-cm depth. Seedling emergence was recorded 1 wk after seeding. Seedling survival, root rot severity, and shoot and root dry weights were measured 4 wk after seeding.

Impact of root rot on nodulation Chickpea seed was planted into soil over a range of inoculum concentrations to produce seedlings with root rot severity levels ranging from healthy to severely diseased. The roots were separated into five disease severity categories. The level of nodulation and root dry weight were determined for each of 50 plants from each disease severity category.

Host Range Alfalfa, barley, white and black dry bean, canola, chickpea, alsike clover, red clover, flax, lentil, oat, pea, soybean, and red spring and durum wheat were assessed for susceptibility to seedling damping-off caused by *R. solani* isolate CKP-1. Seed of each species were planted into both infested and noninfested soil.

Seed Treatment Seed of chickpea B-90 was treated with APRON MAXX at 6.25 or 12.5 g ai/100 kg seed, or with CROWN (carbathiin, 92 g/L + TBZ, 68 g/L SU) at 90.0 g ai/100 kg seed. An experimental plot was established on 18 May, 2001 at Brooks, Alberta. *Rhizoctonia solani* was incorporated at the time of seeding. Nontreated seeds were planted as inoculated and noninoculated controls. Emerged seedlings were counted on 11 June. At maturity, plants were harvested and seeds were weighed to determine yield.

Results

Pathogenicity

Of 17 pathogenic strains isolated from samples collected in a disease survey, five were *R. solani*. All *R. solani* isolates caused 100% mortality in chickpea seedlings (Fig. 2).

Impact of seeding depth on severity of root rot and seedling blight

Emergence was lower and root rot was more severe at 5-cm compared to 2-cm seeding depth in inoculated soil, but seedling growth was not affected by seeding depth in clean soil (Fig. 3). In infested soil, root weight was not affected by seeding depth, but shoot weight was lower at 5-cm than at 2-cm depth.

Impact of root rot on nodulation

Intermediate and high levels of root rot reduced the number of nodules per plant for both cultivars (Fig. 4). For Sanford, even low levels of root rot reduced root weight. For Tyson, root weight did not decline until severity ratings reached 3 and 4.

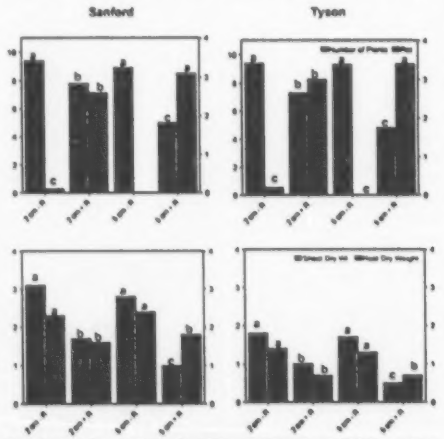

Figure 3. Impact of seeding depth and inoculation with *Rhizoctonia solani* (AG 4) on seedling emergence, shoot and root growth, and root rot severity in chickpea

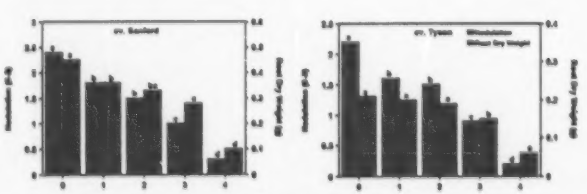

Figure 4. Effect of rhizoctonia root rot severity on level of nodulation in seedlings of two chickpea cultivars grown under controlled conditions

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Host range

Inoculation with *R. solani* caused severe seedling damping-off in alfalfa, canola, chickpea, red and alsike clover, flax, lentil, pea and durum wheat (Figs. 5 A-B). Barley, dry bean, soybean, oat and red spring wheat were relatively unaffected by seedling damping-off. Most species, including those not susceptible to damping-off, developed root rot symptoms and were shorter than the noninoculated controls (Figs. 5 C-D).

Seed treatment

Emergence and seed yields were higher for all seed treatments in the trial than for the inoculated control (Fig. 6). Emergence and yield were similar among all seed treatments and the noninoculated control.

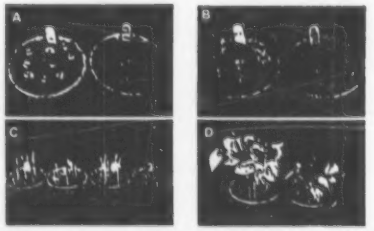

Fig. 5. Seedling blight caused by *Rhizoctonia solani* killed most pea (A) and canola (B) seedlings. Barley (C) and bean (D) survived, but root rot severely inhibited growth

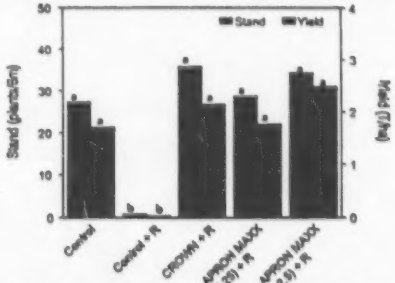

Figure 6. Effect of seed treatment on seedling emergence and seed yield of chickpea in field trials inoculated with *Rhizoctonia solani* (AG 4) at Brooks AB in 2001

Discussion

Rhizoctonia solani was isolated from a significant number of fields with chickpea root rot symptoms. Many of these isolates were highly virulent and produced seedling damping-off in a wide range of species under greenhouse conditions. These virulent *R. solani* isolates all belonged to anastomosis group AG-4. Most of the field crops grown in the region showed some degree of susceptibility, but cereals, dry beans and soybeans were less susceptible than pulses and canola. *R. solani* not only injures the roots directly, but also attacks the nodules containing nitrogen-fixing bacteria. Both Crown and Apron Maxx improved emergence and seed yield over the inoculated control to levels found in the noninoculated control. Integrating seed-treatment fungicides with use of high quality seed and shallow seeding provides a more efficient and reliable agronomic package for infested fields than any single practice on its own.